Bulletin 128 Mineral Technology 18

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FRANKLIN K. LANE, SECRETARY
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BY

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PREFACE.

For years American manufacturers of tile and white ware have been dependent on the importation of foreign kaolin, chiefly in the form of English china clay, for their high-grade material. In 1916, for example, 229,093 tons of such kaolin were imported, valued at $1,377,106, at the port from which it was shipped. At the same time there were known to be available in Georgia and South Carolina large quantities of kaolin of a high degree of purity, except that it contained certain color-giving minerals, especially iron and titanium compounds, and had an abnormal shrinkage. Heretofore this material has been available only for the paper trade and for some lower grades of pottery. Investigations carried on by the division of mineral technology of the Bureau of Mines have shown that the impurities may be readily and cheaply separated and the kaolin so modified in its physical characteristics, both as to shrinkage and to the development of color on burning, that it is comparable with the best English fire clay for many pottery purposes.

By the addition of a small amount of sodium hydroxide, this amount being carefully controlled by chemical analysis, the kaolin colloids may be so deflocculated that the clay remains in suspension in water through long periods of time, allowing the small particles of heavier minerals to settle out readily. On neutralizing afterwards with sulphuric acid, the clay readily settles and may then be filtered and dried as usual.

As a result of laboratory experiments, cooperative experiments were conducted with the Georgia Kaolin Co. at Dry Branch, Ga., and a plant built in accordance with the facts discovered in the laboratory. As a result, many tons of kaolin have been purified at a cost of less than 50 cents a ton, producing thereby a material which has a market value nearly twice that which could be obtained for the kaolin for the purposes to which it was previously put. The purified china clay produced has been further investigated in potteries on an extensive scale through the cooperation of the Zanesville Mosaic Tile Co., the Mayer China Co., and the Beaver Falls Art Tile Co. It has been shown that in vitreous chinaware this purified American kaolin can be successfully substituted for all of the ball clay heretofore used and for at least 50 per cent of the English china clay. Better still, in the tile industry whiter and stronger tile can be and are being made from

this treated Georgia kaolin and American feldspar by substituting them entirely for the English china clay and Cornwall stone heretofore used.

America should, accordingly, be largely independent, and, with further experiments, probably entirely independent of imports of foreign material for the white-ware industries. The details of the work are described in the following pages.

CHARLES L. PARSONS,
Chief, Division of Mineral Technology.

REFINING AND UTILIZATION OF GEORGIA KAOLINS.

By Ira E. Sproat.

INTRODUCTION.

The question "Why can not American kaolins be substituted for English china clay?" has been asked time and time again, and more often since the beginning of the present war in Europe, which has threatened to cut off the supply of European clays imported from abroad. The answer to this question has invariably been, that the domestic kaolins are not as pure and uniform in composition as the imported clays.

This demand for white-burning American clays is of such economic importance that it was considered advisable to determine whether some of our vast deposits of impure white clays could not be refined sufficiently to permit their being substituted for the foreign materials.

Up to the present time mechanical principles only have been applied in the refining of kaolins, but in order to keep pace with the increasing requirements for better quality and uniformity of product, the application of the principles of colloidal chemistry is necessary.

The investigation described in this report was carried on to determine the practicability of applying technical control of clay disperse systems to the refining of kaolins and the utilization of the prepared clay in the manufacture of vitreous china and wall tile.

It is hoped that this report will prove a stimulus to the clay-washing industry; will point out a method of refining certain American clays, and will lead to the substitution of domestic kaolins for imported china clays by manufacturers of high-grade ceramic wares.

SECONDARY KAOLINS OF GEORGIA AND SOUTH CAROLINA.

Immense deposits of secondary kaolins underlie certain areas in Bibb, Twiggs, Wilkinson, Washington, Glasscock, Jefferson, and Richmond Counties, in Georgia; and Aiken, Edgefield, Lexington, and Kershaw Counties, in South Carolina. As these sedimentary kaolins in the Cretaceous strata of Georgia and South Carolina occur in large deposits which run very high in clay substance, and

in some of their physical properties are not unlike the English china clay, it was thought advisable to select these kaolins as a basis for the experiments.

PRINCIPAL DEPOSITS OF SECONDARY KAOLINS.

A general study of the principal kaolin deposits of South Carolina and Georgia was made by Robert Back, formerly of the Bureau of Mines, in 1913, under the direction of C. L. Parsons, chief mineral technologist. The following description of the nature of the different kaolin deposits of Georgia and South Carolina is taken from Mr. Back's field notes, supplemented by the writer's observations in the Dry Branch district of Georgia.

There are two great areas; the Aiken district, in Aiken County, South Carolina, and the Dry Branch district, in Bibb and Twiggs Counties, Georgia, which are being worked extensively to-day. There are a number of other deposits both in Georgia and South Carolina which in quality and extent rival those of the Dry Branch and Aiken areas, but they are located farther from railroads and have not been worked to any great extent. The deposits in Georgia have been described in detail by Veatch,[a] and those of South Carolina by Sloan.[b]

KAOLIN MINING IN THE AIKEN DISTRICT, SOUTH CAROLINA

Kaolin is mined in the Aiken district from open cuts with gravity drainage or from pits which are drained by steam pumps. A number of kaolin mines have been opened in this district, chief of which are those of McNamee & Co., South Carolina Clay Co., Paragon Kaolin Co., Immaculate Kaolin Co., and Peerless Clay Co.

MCNAMEE & CO.

The property of McNamee & Co. is situated about one mile from Bath and near Horse Creek. The kaolin is mined by open cuts having gravity drainage. The overburden, which is about 30 feet in depth, is removed with a steam shovel. The clay bed is known to attain in places a thickness of about 15 feet, the upper 2 feet and lower 7 feet of which are full of grit and sand and are thrown away. This clay is simply air-dried and sold to the paper trade.

SOUTH CAROLINA CLAY CO.

The South Carolina Clay Co. operates an open-cut mine near Horse Creek and not far from that of McNamee & Co. The kaolin deposit is about 8 feet thick and the overburden ranges from 20 to

[a] Veatch, Otto, Second report on clay deposits of Georgia: Bull. 18, State Geol. Survey, 1909, 453 pp.

[b] Sloan, Earle, A preliminary report on the clays of South Carolina: Bull. 1, ser. 4, State Geol. Survey, 1904, 171 pp.

40 feet thick. The top 8 to 10 inches of kaolin, which is badly stained with iron, is thrown away, and the underlying kaolin, yellowish in color, is dried in the open air and sold to the pigment and crayon trades.

PARAGON KAOLIN CO.

The mines of the Paragon Kaolin Co. are about 1½ miles from Langley Station. This company is operating two open-cut mines with a daily capacity of about 100 tons. The clay bed is about 12 feet thick. The overburden, which varies in thickness from 30 to 40 feet, is removed with mules and carts. The kaolin obtained from these two mines is rather soft and mealy, and the output is sold exclusively to the paper trade.

IMMACULATE KAOLIN CO.

The mine of the Immaculate Kaolin Co. is located about 2 miles southeast of Langley Station. The clay deposit in this mine reaches a thickness of about 25 feet and is very white and free from grit, especially in the lower part of the bed. The overburden, which reaches a thickness of 40 feet, is removed with a cable excavator. The clay is sold directly and exclusively to the paper trade.

PEERLESS CLAY CO.

The Peerless Clay Co. operates a mine 2 miles southeast of Langley Station, the clay deposit being very similar to that mined by the Immaculate Kaolin Co.

KAOLIN MINING IN THE DRY BRANCH DISTRICT, GEORGIA.

In March, 1916, there were three companies actively engaged in the mining and marketing of secondary kaolins within a radius of three miles of Dry Branch. The mines are all open-cut mines.

GEORGIA KAOLIN CO.

The Georgia Kaolin Co. is the only one in this district actively engaged in washing kaolin. The clay as mined is highly plastic, has a high strength, and burns to a good white, but if glazed the color becomes a decided cream. The product is sold to the paper trade, pigment manufacturers, and some ceramic industries. A view of a face in this mine is shown in Plate I, *A*.

AMERICAN CLAY CO.

The American Clay Co. sells its entire output to the paper trade. The clay is not washed and the only mechanical treatment it receives is crushing after being air-dried. A washing and refining plant is being built. This clay has a good plasticity and burns to about the

same color as the clay mined by the Georgia company, but is softer and more mealy and has a lower tensile strength. A view of the claybank in this mine is shown in Plate I, *B*.

JOHN SANT CLAY CO.

The John Sant Clay Co. mines and pulverizes its clay for use in the manufacture of white-ware pottery, wall tile, and other ceramic wares. The clay from this mine is very hard, fine grained, and burns to a good color, but lacks uniformity in composition, which is partly due to impurities. If this clay were to be refined it would doubtless find a much wider application in the ceramic industries.

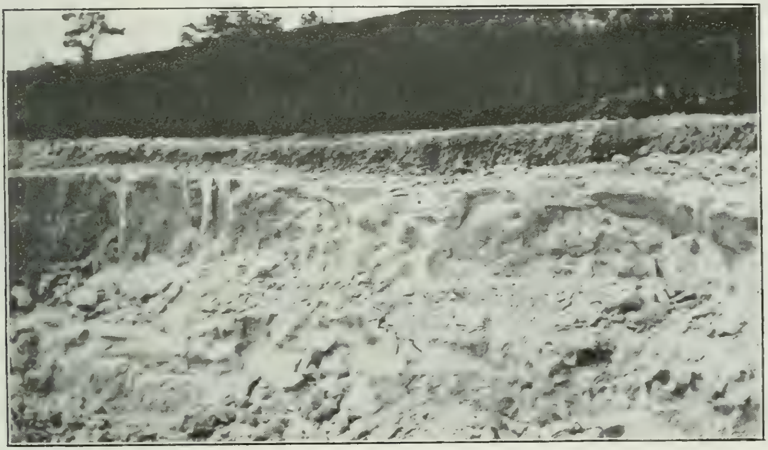
ATLANTA MINING & CLAY CO.

The Atlanta Mining & Clay Co. formerly operated a mine and washing plant in this district. The property has been idle for the past year or more.

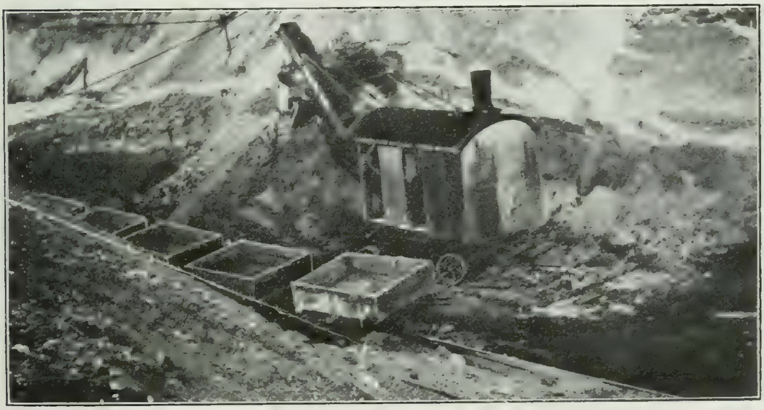
PROBABLE CAUSES OF VARIATION IN PHYSICAL PROPERTIES OF THE CLAYS.

The variation in physical properties of kaolin from different mines, as noted above, is evidently due to the variable conditions under which the deposits were laid down, the denser and harder clays having been formed under conditions of complete deflocculation and disintegration of clay grains, whereas the clays of lesser density and tensile strength have probably been deposited while the grains were in a more flocculated and coagulated condition. In other words, the extent of dispersion at the time of deposition has affected the physical properties of the clay. As a result the clay from one of the mines mentioned is hard and weak and must be finely ground before it will blunge satisfactorily with water; another mine produces soft mealy clay which is easily blunged with water without any preliminary treatment; and still another mine yields a soft, highly plastic, and strong clay which contains irregular layers or pockets of fine-grained flinty clay of low tensile strength, that is so hard that much of it must be thrown away, as it will not blunge in the washers. The harder clays contain less impurities than the softer ones, indicating that the ancient ocean or sea, which acted as a huge washing plant in refining and sorting these sediments, deflocculated some clays and caused the impurities to settle out more readily.

A. VIEW IN OPEN-CUT KAOLIN MINE IN THE DRY BRANCH DISTRICT, GA., SHOWING OVERHEAD TRAMWAY.



B. VIEW IN ANOTHER KAOLIN MINE, DRY BRANCH DISTRICT.



C. REMOVING OVERBURDEN WITH STEAM SHOVEL.

MINING METHODS AND TREATMENT.

KAOLIN MINING IN THE DRY BRANCH DISTRICT.

Open-cut mining is universally practiced at the kaolin mines in the Dry Branch district, owing to the fact that the overburden is so soft that any timbering would have to be water-tight in order to keep out sand and iron-stained silt in rainy weather.

REMOVAL OF OVERBURDEN.

Figure 1 shows graphically the strata in the mine of the Georgia Kaolin Co. and is typical of the strata generally found in mines of this district. However, the thickness of overburden will vary from about 10 feet along the ravines to probably 100 feet below the crest of the hill.

FIGURE 1.—Cross section of strata in a kaolin mine in the Dry Branch district.

The removal of this overburden is an important part of the mining operations. To remove such large amounts of material economically and with dispatch and dispose of them has been one of the main problems. However, until lately not much attention has been given it.

At present (March, 1916) two of the companies mentioned are using steam shovels for removing the overburden, and it will probably be only a short time until the overburden is stripped back far enough (200 feet) from the clay face or breast to avoid contamination in case of caving during rainy weather. A steam shovel at work is shown in Plate I, *C*. Another company removes the overburden with pick and shovel, removing just enough to expose the face of the clay bank, with the result that sometimes after a rain the overburden caves, filling the pit and staining the clay. The drag scraper which was formerly used by two of the companies is shown in Plate II, *A*.

MINING THE CLAY.

In the three mines mentioned the kaolin is mined with pick and shovel, the clay being mined economically and easily in this way, owing to the jointing. Veatch [a] in describing the mining of kaolin at the mine of the Georgia Kaolin Co., says:

> A structural feature which has an economic application is the jointing. The joints have no definite system or fixed direction, and may be oblique, vertical, or horizontal,

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[a] Veatch, Otto, Second report on the clay deposits of Georgia: Bull. 18, State Geol. Survey, 1909, p. 127.

and the bed may be minutely jointed or there may be only large cracks at wide intervals. The jointing has the appearance of being due to shrinkage of the clay mass, and not to orogenic movements.

By undermining the clay at the base of the face or breast and driving long wooden or steel stakes down into the clay near the edge of the breast, large chunks are split off, advantage being taken of the jointing of the clay. The clay split down from the bank is broken into lumps of a size that can be conveniently loaded. In the mines of the American Clay Co. and John Sant Clay Co., where the clay is not given a subsequent treatment other than grinding, these small lumps are hand sorted and the iron stains and sand pockets are cut out with hoe-shaped knives. The irregular jointing of kaolin in two different mines is shown in Plate II, *B* and *C*.

REMOVING CLAY FROM PIT.

Each company uses different methods in removing the mined clay from the pit, the method used depending upon the output of the mine, the topography of the surface, and the subsequent treatment of the clay.

JOHN SANT CLAY CO. MINE.

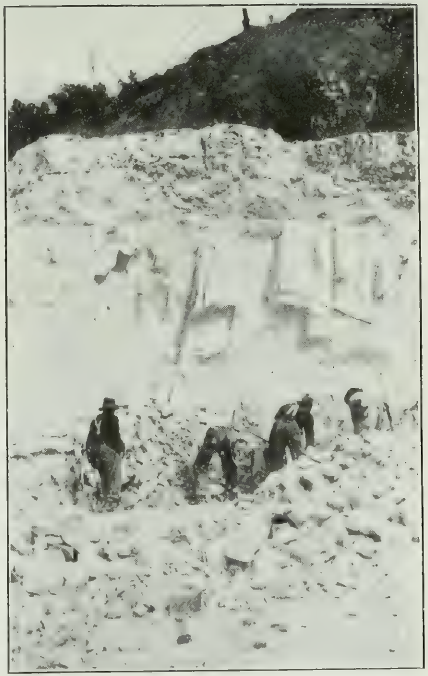
The mine of the John Sant Clay Co. is located about 1 mile from their drying sheds, which are situated along the Macon, Dublin & Savannah Railroad, and the output is small. The clay is shoveled into wagons and hauled to the open-air drying sheds where it is allowed to dry for several weeks. When dry the clay is ground in a set of corrugated rolls, screened, and sacked for shipment to the pottery trade.

The drying sheds (See Pl. III, *A*) consist of three to six tiers of superimposed racks about 15 feet wide, the clay being piled on the racks to a depth of about 3 feet. The bottom of the racks is formed of movable scantlings or pine railings. As the clay on the lowest tier becomes dry it is dropped on the floor, and the loads on each superimposed tier are dropped in succession. The dried kaolin dumped on the floor is broken with mauls or in roll crushers.

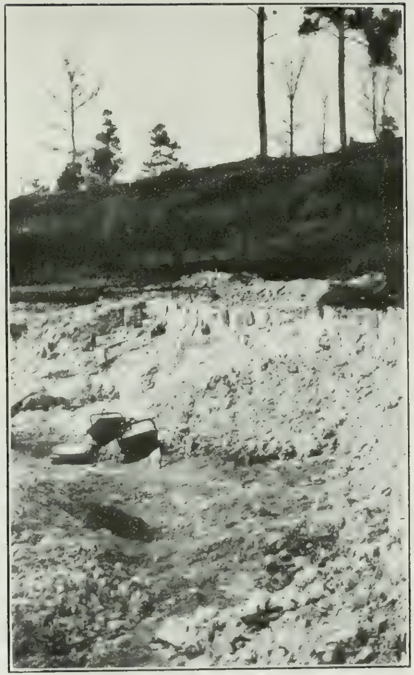
AMERICAN CLAY CO. MINE.

At the mine of the American Clay Co. the clay is elevated out of the pit with an overhead tramway which transports and dumps the clay into small loading bins at the top of the pit. The clay is then dumped into cars, which are drawn from the loading bins to the open-air drying sheds by a wire cable and winding drum. The clay is allowed to dry for several weeks, when it is shaken down to the bottom of the shed, hammered and cut up into small lumps about the size of a man's fist, loaded into cars, and shipped exclusively to the paper trade.

A. REMOVING OVERBURDEN WITH DRAG SCRAPER.



B. VIEW IN OPEN-CUT KAOLIN MINE, SHOWING IRREGULAR JOINTING OF CLAY.



C. ANOTHER VIEW SHOWING JOINTING OF CLAY.

GEORGIA KAOLIN CO. MINE.

In the mine of the Georgia Kaolin Co. the clay is merely broken in pieces small enough to be loaded by two men, as the subsequent treatment of the clay does not require breaking into small pieces at this stage. The clay is elevated from the pit by an overhead tramway or by cars which are pulled out of the pit by a steel rope and winding drum. Both the cars and buckets automatically dump their clay into a large storage shed, which holds enough clav to run the washing plant for a week.

KAOLIN REFINING IN THE DRY BRANCH DISTRICT.

Only one company, the Georgia Kaolin Co., in this district is actively engaged in the refining of kaolin. The method of washing clay at this plant is similar to the refining process used in refining the primary kaolin of the southern Appalachian district, which has been described in detail by Watts,[a] so only a mere outline of the washing process will be given here. It consists of seven different operations, which are as follows:

1. Thorough blunging of the clay with water, in rectangular blungers, which are about 10 feet long, 4 feet wide, and 4 feet deep.
2. Floating the slip through narrow troughs about 50 feet long with an average width of about 2 feet, the width of trough depending on the rate of flow required to settle out the impurities.
3. Screening the slip through a 110-mesh rotary screen.
4. Concentrating the slip in large concrete tanks, which are about 75 feet long, 25 feet wide, and 5 feet deep, where it is allowed to stand for about 48 hours, when the supernatant liquid is drawn off and the thickened clay slip run into a small retaining tank.
5. Filter pressing the thick clay slip, which is pumped from the small retaining tank into the filter press at a pressure of 100 pounds.
6. Drying the filter-press cakes, which contain about 25 per cent of water, in tunnel driers heated by exhaust steam, or in open-air drying sheds.
7. Crushing the thoroughly dried cakes into small pieces in corrugated rolls.

Open-air driers for drying the filter-press cakes are shown in Plate III, *B*. A view of the refining plant is shown in Plate III, *C*.

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[a] Watts A. S., Mining and treatment of feldspar and kaolin in the southern Appalachian region: Bull. 53, Bureau of Mines, 1913, p. 72.

IMPURITIES IN GEORGIA KAOLINS.

The following is a chemical analysis of a sample of kaolin taken from the pit of the Georgia Kaolin Co., as reported by S. W. McCallie:

Composition of sample of kaolin.[a]

	Per cent.
Moisture at 100° C	1.22
Loss on ignition	13.46
SiO_2	44.76
Al_2O_3	38.41
Fe_2O_3	.63
CaO	.20
MgO	.09
Na_2O	.09
K_2O	.35
TiO_2	1.37

From this analysis it is seen that the chief color-imparting oxides are Fe_2O_3 and TiO_2. The source of these oxides is best shown by the following results of a microscopic examination of a sample of clay from the mine of the Georgia Kaolin Co., by F. B. Laney, of the United States Geological Survey:

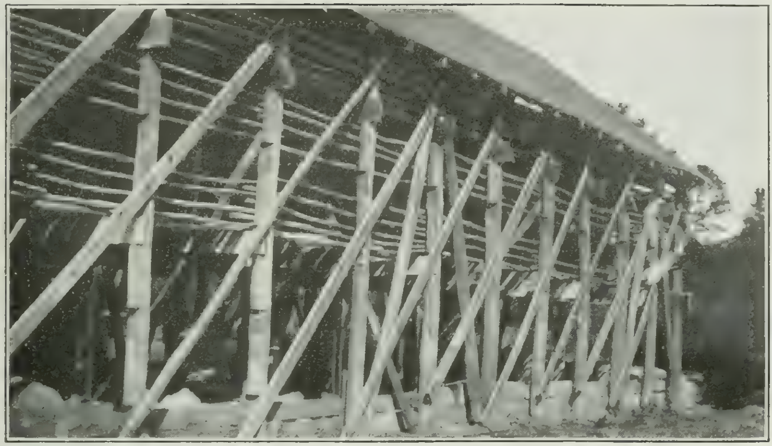
Associate minerals found by microscopic examination of kaolin.

Quartz.
*Partly decomposed feldspar, often stained with iron oxide.
*Wad—small pisolites of manganese oxide.
*Limonite.
Muscovite.
*Magnetite.
*Hematite.
*Ilmenite.
Zircon.
*Rutile.
Apatite.
*Tourmaline.
Corundum.
Monazite.
*Iron—minute particles broken off from the crushing machinery.

The minerals marked with an asterisk are the minerals that tend to give a cream color to a burned china body when Georgia kaolin is one of the constituents of the body.

Only a small part of these impurities is removed by the present methods of refining, owing to the fact that the most of the color-imparting minerals are present in a very fine state of subdivision, as the coarser impurities settled out when the clay was being deposited. In fact, most of the color-imparting particles will pass a 260-mesh sieve, and some are much finer. Besides being finely subdivided, these impurities are completely coated with clay, which prevents their being settled out, regardless of their higher specific gravity, without a large loss of clay. This clay coating is not removed to any great extent on prolonged blunging. Blunging for two hours will not disperse the clay particles. Grinding in a ball mill has a greater

[a] Veatch, Otto, Second report on clay deposits of Georgia: Bull. 18, State Geol. Survey, 1909, p. 128.



A. OPEN-AIR DRYING SHEDS FOR CRUDE CLAY.

B. OPEN-AIR DRYING SHEDS FOR WASHED CLAY.

C. KAOLIN REFINING PLANT NEAR DRY BRANCH, GA.

tendency to produce complete disintegration, but such treatment is not economical to use in the washing of kaolins. Therefore, in order to obtain complete dispersion of the clay grains and the resulting separation of the coloring minerals from the clay it is necessary to consider the colloidal nature of clay, and apply chemical principles thereto.

EFFECTS OF ELECTROLYTES ON CLAY BODIES.

LITERATURE.

Probably one of the first persons who noticed the effect of alkalies on clay was Brongniart,[a] who in 1844 claimed that adding 3 per cent of potash improved the pottery bodies with which he worked.

Shortly after this, Hartmann [b] described the use of alkalies in casting.

Seger [c] also noticed some effects of alkalies in ceramic bodies.

Zebisch,[d] who carried on one of the first scientific investigations of the effect of bases on clays, noticed that basic substances have an angular sharp-cornered form while in a solution of water, and that acid substances have a round smooth form. He offers this as a possible explanation of the effect of bases on clays.

Goetz [e] in his German patent advises the use of soda with or without cinnabar in the casting of porcelain and stoneware.

In 1895 Hagedorn[f] claimed that a mixture of clay, chalk, quartz, and ground glass made a body requiring a smaller amount of water than certain other ceramic mixtures. This is probably due to the fact that alkalies dissolved from the ground glass and caused deflocculation of the clay.

Kosmann [g] claims that a certain amount of silicic acid is dissolved from the clay substance by soda, and that the silicic acid thus dissolved causes the clay slip to become more liquid.

New developments in colloidal chemistry about this time helped Lottermoser[h] to throw light on some of the present-day views of the effect of alkalies on colloidal gels.

Weber [i] claims in his patent that by using a plastic bond clay in a body together with soda, ammonia, potash, sodium silicate,

[a] Brongniart, A., Traité des arts céramiques ou des poteries, 1844, pp. 468–469.

[b] Hartmann, C., Die Tonwarenfabrikation (1850): Sprechsaal, Jahrg. 27, 1894, p. 1028.

[c] Seger, Hermann, Japanisches Porzelian und dessen Dekoration: Tonindustrie Ztg., Jahrg. 15, 1891, p. 813; Seger's Gesammelte Schriften, 1897, p. 573.

[d] Zebisch, A., Sprechsaal, Jahrg. 27, 1894, p. 105; Jahrg. 28, 1895, p. 303.

[e] Goetz, Karl, German patent 76247, 80b, Oct. 23, 1891; Ueber Sodaschlicher, Sprechsaal, Jahrg. 27, 1894, pp. 637, 685, 738.

[f] Hagedorn, Robert, and Hagedorn, Hermann, German patent 90697, Oct. 23, 1895.

[g] Kosmann, Dr., Ueber die Verflüssigung von Thonbrei durch Soda: Tonindustrie Ztg., Jahrg. 19, 1895, p. 382.

[h] Lottermoser, Alfred, Ueber anorganische Colloïde: Sammlung Chem. und chem.-techn. Vorträge, Bd. 6, 1901, pp. 161–240.

[i] Weber, E., German patent 158496, 80b, Aug. 14, 1902.

molasses, and soap it is possible to cast with nonplastic ingredients a body as thick as 10 mm. in diameter. He states that such a slip will cast as well as the finer grained porcelain and stoneware slips.

L. J. Briggs [a] and others, of the U. S. Bureau of Soils, used ammonia to dissolve the colloids in soils. It was found that ammonia was most effective in deflocculating soils containing a low percentage of soluble salts. For instance, little effect was noticed on soils containing more than 1 per cent of soluble salts. The investigators mentioned also noticed that when the soil contains a considerable amount of lime or magnesium carbonate, flocculation occurs, usually becoming more pronounced on the addition of ammonia.

Förster [b] notes that the viscosity of clays is decreased by small additions of alkalies. He claims that the negatively charged OH ion repels similarly charged clay particles. He also notes that the OH ion is absorbed by the clay. Spangenberg [c] claims that the OH ion is absorbed by the clay particles and the so-charged clay particles repel each other, causing a liquefaction of the clay slip.

Förster [d] claims that the Ca ion dissolved by clay slips from the plaster molds prevents to a certain extent the deflocculating action of the OH ion. In order to prevent this he advises the use of Na_2CO_3 instead of NaOH, thereby changing the Ca ion to harmless $CaCO_3$.

The German patent 201404 [e] issued in 1906, states that the plasticity of kaolin, clay, and ceramic mixtures can be increased by the addition of tannic acid. It also states that tannic acid with an excess of alkali when added to clay causes a certain fluidity in the slip, which on the addition of more tannic acid, again thickens. Certain other organic acids may be used in the place of tannic acid.

The introduction of alum [f] to accelerate sedimentation was another important step in the clay-washing industry. Hirsch,[g] Simonis,[h] Mellor,[i] Rieke,[j] and others studied the effect of soluble sulphates on clays. Most important is probably Rieke's work, in which he showed that $MgSO_4$, $CaSO_4$, $FeSO_4$, $ZnSO_4$, $CuSO_4$, $CoSO_4$, $Al_2(SO_4)_3$, and MgO increased the viscosity of a Zettlitzer kaolin slip.

[a] Briggs, L. J., Martin, F. O., and Pearce, J. R., Centrifugal method of mechanical soil analysis: Bureau of Soils Bull. 24, 1904, p. 24.

[b] Förster, F., Ueber das Giessen des Tons: Chem. Ind., Jahrg. 28, 1905, pp. 733–740.

[c] Keppeler, Gustav, and Spangenberg, Albert, Verfahren Kaoline, Tone und aus hergestellte keramische Massen plastischer zu machen: Chem. Ind., Bd. 31, 1908, p. 592.

[d] Förster, F., Loc. cit.

[e] Keppeler, Gustav, and Spangenberg, Albert, German patent 201404, 80b, Aug. 29, 1906.

[f] Ries, Heinrich, Clays of the United States east of the Mississippi River: Prof. Paper 11, U. S. Geol. Survey, 1903, p. 35.

[g] Hirsch, H., Verhalten von Ton in Salzlosüngen: Tonindustry Ztg., 1904, p. 491.

[h] Simonis, M., Weitére Beiträge zum Verhalten von Tonen und Magérungsmitteln gegen Elektrolyte: Sprechsaal, Jahrg. 36, 1906, p. 1186.

[i] Mellor, J. W., Studies on clay slips: Trans. Eng. Cer. Soc., vol. 6, 1906–7, pp. 161–170.

[j] Rieke, Reinhold, Ueber die Wirkung löslicher Sulfate auf Kaoline und Tone: Sprechsaal, Jahrg. 43 1910, p. 709.

Alkalies were also used by Schwerin [a] in his electrical method of purification of clays. Before the clay slip was treated with electricity it was deflocculated with an electrolyte to permit the coarser impurities to settle. The finer impurities were then removed by electrolysis.

Ashley [b] found that the color of clays in which iron is one of the bases would be improved if the clay was blunged with hydrochloric acid, settled, and the overlying water drawn off.

Ashley [c] also reports Keppler's patent on improving clays by deflocculating with alkali, making an addition of colloid matter from humus, and reprecipitating all together by the addition of an acid.

Bleininger,[d] in summarizing his results on the electrical separation of clay, says the use of caustic soda and other electrolytes brings about a condition of minimum viscosity which greatly assists in the separation of quartz and feldspar from the clay.

Brown and Howat [e] found that by deflocculating kaolins with caustic soda or silicate of soda their color was improved and the drying shrinkage decreased, but the burning shrinkage increased.

Bleininger [f] states:

> The washing of kaolinitic clays may be decidedly improved as far as the quality of the product is concerned by adding to the water in the blunger a definite small amount of caustic soda or a mixture of caustic soda and sodium silicate. This treatment improves the color of most clays, enriches their content in clay substance, decreases the drying shrinkage, but tends to increase the burning shrinkage.

EXPERIMENTS WITH KAOLINS OF SOUTH CAROLINA AND GEORGIA.

PRELIMINARY INVESTIGATION.

The preliminary tests on the different secondary kaolins of South Carolina and Georgia were made by Robert Back in 1913–14 at the Washington laboratory of the bureau. Back investigated different methods of refining these secondary kaolins, and compared the color of the refined product when burned and glazed at cone 10 to that of English china clay burned under the same conditions. He found that by thoroughly deflocculating kaolin from the Dry Branch district with a small measured quantity of caustic soda the impurities could be settled out with greater ease. The product showed sufficient

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[a] Stoermer, M., Ein neues elektrisches Tonreinigungsverfahren: Tonindustrie-Ztg., Jhrg. 36, 1912, pp. 1283–1284, Schwerin, —, Electrical process for the purification of clays; Trans. Eng. Cer. Soc., vol. 12, 1912–1913, pp. 36–65; Bleiniger, A. V., Use of sodium salts in the purification of clays and in the casting process, Tech. Paper 51, Bureau of Standards, Sept. 25, 1915, pp. 14–19.

[b] Ashley, H. E., The technical control of the colloid matter in clays: Trans. Am. Cer. Soc., vol. 12, 1910, p. 802.

[c] Ashley, H. E., Op. cit., p. 803.

[d] Bleininger, A. V., Note on the electrical separation of clay: Trans. Am. Cer. Soc., vol. 15, 1913, p. 343.

[e] Brown, G. H., and Howat, W. L., The use of deflocculating agents in the washing of clays and the effect of the process upon the color: Trans. Am. Cer. Soc., vol. 17, 1915, p. 87.

[f] Bleininger, A. V., Use of sodium salts in purification of clays and in the casting process: Tech. Paper 51, Bureau of Standards, Sept. 25, 1915, p. 38.

improvement in color when made up into hard, fire-glazed porcelain bodies to justify the washing of several tons of the Dry Branch (Ga.) kaolin at one of the washing plants operating in that district. The results of Back's work have been published by permission of the bureau in the Transactions of the American Ceramic Society.[a]

PURPOSE OF PRESENT TESTS.

In order to determine whether some practical method of refining the secondary kaolins of Georgia on a commercial scale could be devised, the Bureau of Mines arranged a cooperation agreement with the Georgia Kaolin Co., Dry Branch, Ga., and this work was begun by the writer in March, 1915.

EFFECT OF ALKALIES, ACIDS, AND SALTS ON GEORGIA KAOLIN SLIP.

Much work has been done in this country and abroad to determine the effect of electrolytes on clay in suspension in water, and in nearly every investigation carried on in this country Georgia kaolin was included among the clays tested. Therefore only a brief summary of the effect of alkalies, acids, and salts on Georgia kaolin suspensions, as determined in experiments by the writer, will be given here.

EFFECT ON VISCOSITY OF SLIP.

It is well known that alkalies in small amounts tend to increase the state of dispersion of clay-water systems, the result being a decrease in viscosity of the system. This breaking up of the larger clay particles into smaller ones is plainly shown by the following mechanical analyses of two samples of washed Georgia kaolin, one of which was washed in a solution containing 0.075 per cent NaOH. These analyses were made with a Schultze elutriation apparatus having an overflow of 80 c. c. per minute.[b]

TABLE 1.—*Results of mechanical analyses of washed Georgia kaolin.*

Size of clay particles.	Washed Georgia kaolin.	Georgia kaolin washed with 0.075 per cent NaOH.
Mm.	*Per cent.*	*Per cent.*
0.110	0.27	0.28
.0765	.42	.45
.0578	.33	.30
.0340	4.40	.92
.0187	2.36	2.30
.0100	15.70	9.04
	76.52	86.61

[a] Back, Robert, Effects of some electrolytes on clays: Trans. Am. Cer. Soc., vol. 76, 1914, pp. 515–546.

[b] For description of this apparatus see Watts, A. S., Mining and treatment of feldspar and kaolin in the southern Appalachian region: Bull. 53, Bureau of Mines, 1913, p. 46.

This table shows that the particles that were larger than 0.034 mm. were little affected by hydroxide; therefore they were chiefly impurities and not colloidal clay.

On the other hand, many acids and salts have the opposite effect to that of alkalies, causing a coagulation of the clay particles and a resulting increase in the viscosity of the system.

Therefore the effect of the addition of different amounts of electrolytes to a clay-and-water system can be satisfactorily studied by the determination of viscosity. This is best done by the use of a brass efflux tube or viscosimeter. The viscosimeter used by the writer was similar to the one described by Bleininger,[a] with the exception

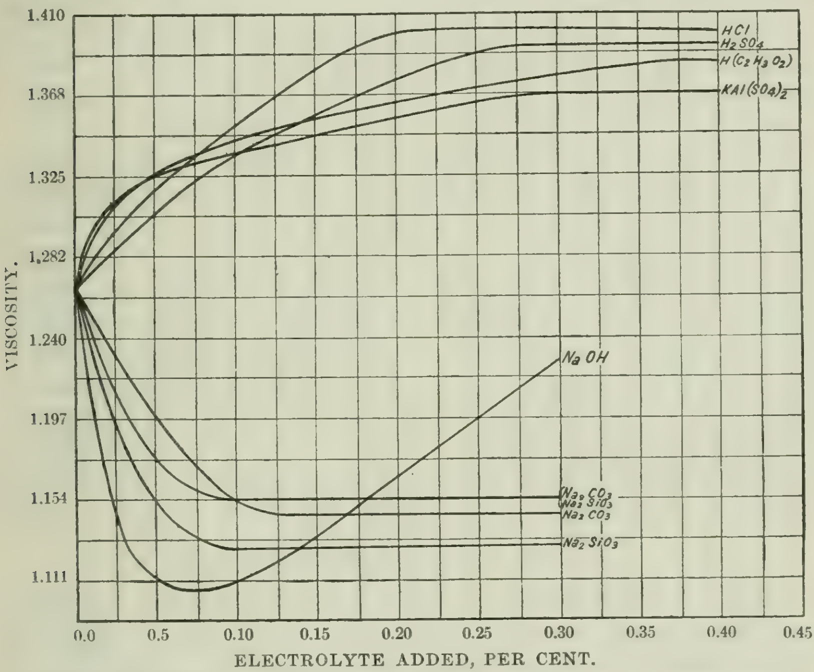

FIGURE 2.—Effect of electrolytes on viscosity of slip containing 20 per cent of Georgia kaolin.

of the size of the efflux, which was $\frac{3}{32}$ instead of $\frac{5}{32}$ inch, as recommended by Bleininger. This reduction in size of efflux is necessary in determining the viscosity of slips containing a small percentage (less than 25 per cent) of solids. All viscosity determinations made by the writer are based on the volume of water that ran through the $\frac{3}{32}$-inch efflux tube in 117 seconds, which is to be understood when mention is made of viscosity determinations throughout this report. The viscosities of all clay suspensions are computed in terms of water by dividing their observed time of flow by 117.

[a] Bleininger, A. V., Use of sodium salts in purification of clays and in the casting process: Tech. Paper 51, Bureau of Standards, Sept. 25, 1915, p. 20.

Figure 2 shows the effect of alkalies, acids, and salts upon the viscosity of a Georgia kaolin slip containing 20 per cent clay. From these curves it is seen that caustic soda caused the greatest drop in viscosity of any of the reagents used, the viscosity reaching a well-defined minimum with an addition of 0.075 per cent of this reagent. On further additions of caustic soda the viscosity at once increased. In the case of sodium silicate and sodium carbonate the decrease in viscosity was not as great as that caused by additions of caustic soda. Also the minimum viscosity is not reached until 0.10 per cent of sodium silicate, or 0.125 per cent of sodium carbonate, is added to the clay-and-water system. A mixture consisting of 50 per cent Na_2CO_3 and 50 per cent Na_2SiO_3 caused a smaller drop in viscosity than either of these reagents alone, the minimum viscosity being reached with 0.10 per cent of the mixture. Neither sodium carbonate, sodium silicate, or a mixture of the two showed any tendency to increase the viscosity.

In the case of the coagulating agents hydrochloric acid showed the greatest coagulating tendency, the mixture reaching a well-defined maximum viscosity upon the addition of 0.2 per cent of the reagent. Acetic acid and alum did not increase the viscosity as much as hydrochloric acid, the maximum viscosity produced by these reagents being 1.384 and 1.376, respectively, as compared to 1.401 produced by hydrochloric acid; but they were much more active in coagulating the clay particles below 0.05 per cent additions. The addition of 0.4 per cent of acetic acid, or 0.3 per cent of alum, was necessary to reach the maximum viscosity.

In the case of sulphuric acid the maximum viscosity of 1.393 was reached with the addition of 0.275 per cent of the reagent.

EFFECT UPON SEDIMENTATION.

It is also a well-known fact that additions of small amounts of alkalies tend to hold the clay in suspension or in a state of deflocculation which corresponds to decreasing viscosity, while acids and salts have the opposite effect upon the slip, causing a more rapid settling of the clay particles. The slip is then said to be in a state of flocculation, which corresponds to an increase of viscosity.

CONTROL OF THE VISCOSITY OF CLAY SLIP.

The fact that alkalies when added to clay-and-water systems increase the dispersion of the system with resulting decrease in viscosity and increased suspension of the clay particles makes this principle directly applicable to the purification of Georgia kaolins, for the impurities in the Georgia kaolins are coated with clay, which fact makes it impossible to settle the impurities out without a great loss of clay, but when the clay-and-water system is dispersed they are then free to settle. Also the consequent increased suspension

of the clay particles gives a longer time in which impurities may settle before the process becomes uneconomical owing to the settling of clay. The success of any kaolin-refining process making use of these facts depends upon the technical control of the viscosity of the clay-water system. Therefore a study of the factors affecting both the initial and the minimum viscosity was made under the conditions of a commercial washing plant.

FACTORS AFFECTING THE INITIAL VISCOSITY.

It is a well-known fact that present-day kaolin-refining methods are not only wasteful but very inefficient, which is shown clearly by viscosity tests performed by the writer at Dry Branch, Ga. These tests not only point out the cause of inefficiency, but show why better results have not been obtained.

VARYING CLAY CONTENT.

Without some mechanical means of controlling the amount of clay going into the washer, wide variations in the percentage of clay in the slip will occur. These variations are sometimes very great, as is shown in the table following, which shows the variation in clay-and-water content of the slip during a period of one month. From the data in this table it is seen that the percentage of clay varied from 0.6 to 12.7 per cent, with an average of 7.64 per cent for the month. These tests were made at all hours of the day and under varying conditions of weather, temperature, mining operations, and other changing factors, so that the average of 7.64 per cent of clay represents the average conditions found in the washing plant. It can be readily seen that this wide range in composition of slip will affect both the quantity and the quality of the product.

TABLE 2.—*Percentages of clay and water in slip during one month of operation.*

Date.	Hour.	Water.	Clay.	Date.	Hour.	Water.	Clay.
(1916)		*Per cent.*	*Per cent.*	(1916)		*Per cent.*	*Per cent.*
Mar. 20	9.00 a.m.	90.0	10.0	Apr. 7	8.15 a.m.	95.4	4.6
24	10.00 a.m.	91.6	8.4		9.45 a.m.	93.9	6.1
	11.00 a.m.	92.7	7.3		10.00 a.m.	96.0	4.0
25	9.00 a.m.	93.6	6.4		11.00 a.m.	94.4	5.6
	10.00 a.m.	90.2	9.8	8	6.45 a.m.	91.8	8.2
	1.00 p.m.	93.6	6.4		8.15 a.m.	88.9	11.1
26	8.00 a.m.	92.4	7.6		8.30 a.m.	94.2	5.8
	10.00 a.m.	93.6	6.4		8.45 a.m.	94.5	5.5
	12.00 a.m.	94.0	6.0		1.30 p.m.	91.5	8.5
27	8.00 a.m.	92.0	8.0	9	8.30 a.m.	88.9	11.1
	10.00 a.m.	91.8	8.2		10.00 a.m.	92.7	7.3
29	8.00 a.m.	94.8	5.2		2.00 p.m.	91.8	8.2
31	11.30 a.m.	95.6	4.4	10	8.00 a.m.	90.5	9.5
Apr. 1	8.00 a.m.	91.7	8.3		9.00 a.m.	87.3	12.7
2	9.30 a.m.	93.0	7.0		10.30 a.m.	93.9	6.1
3	2.45 p.m.	95.5	4.5		11.30 a.m.	89.4	10.6
5	7.30 a.m.	99.4	0.6	12	7.15 a.m.	86.5	13.5
	8.00 a.m.	92.2	7.8	14	6.30 a.m.	93.4	6.6
	9.00 a.m.	94.2	5.8		8.00 a.m.	91.4	8.6
	10.00 a.m.	88.7	11.3	15	5.00 p.m.	88.6	11.4
	1.30 p.m.	90.9	9.1	16	10.00 a.m.	89.6	10.4
	1.45 p.m.	94.7	5.3		10.30 a.m.	95.2	4.8
	5.00 p.m.	91.8	8.2		1.00 p.m.	91.8	8.2
7	7.15 a.m.	91.8	8.2		4.00 p.m.	91.2	8.8

Average, 7.64 per cent clay.

DEGREE OF BLUNGING.

The effect of different degrees of blunging on the initial viscosity is shown in curves *1*, *3*, and *4* of figure 3. Curves *1* and *3* were plotted from viscosity tests of slips taken direct from the washer or blunger of the plant at which the tests were made, the tests of curve *3* being made in dry weather while those of curve *1* were made in wet weather. From these two curves it is seen that there is a decided increase in viscosity of clay treated during wet weather. This increase is due to the fact that the clay is wet and sticky as it enters the washer, which in turn decreases the blunging action of the washer, causing a decrease in the dispersion of the clay particles with consequent increase in viscosity. It is a well-known

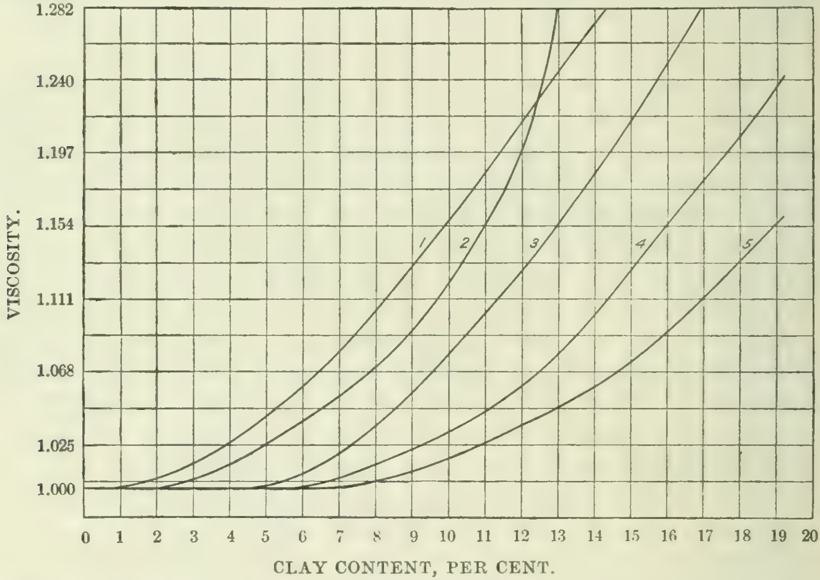

FIGURE 3.—Effects of moisture in clay used, blunging, and additions of alum, on Georgia kaolin slip. *1*, test made during wet weather; *2*, water contained 0.03 per cent alum; *3*, test made during dry weather; *4*, undried clay blunged 2 hours in ball mill; *5*, bone-dry clay blunged in small churn.

fact at kaolin-refining plants that the clay will not settle as quickly in wet weather as in dry weather, and alum is used to precipitate the clay. This fact seems to be contradictory to the above statements, but the reason for the slow rate of settling is not due to increased dispersion but to the decreased percentage of clay in the slip.

The effect of increased blunging action is shown in curve *4* of figure 3. The slips for this test were made from clay taken direct from the mine during dry weather, blunged in a ball mill for two hours, screened through a 120-mesh sieve, and then tested. From this curve it is seen that increased blunging causes an increased drop in the viscosity, owing to increased dispersion.

PREDRYING.

Curve *5* of figure 3 shows the effect of drying clay before blunging with water. These tests were made by blunging bone-dry clay with water in a small household churn. The curve shows that drying produces still greater dispersion with resulting low viscosity.

USE OF ALUM.

The tests represented by curve *2* of figure 3 were made in dry weather, but the feed water contained about 0.03 per cent of alum. From this curve it is evident that small percentages of alum will greatly increase the viscosity, the effect of the alum becoming more pronounced as the percentage of solids in the slip increases.

THE EFFECT OF VARYING VISCOSITY ON CAPACITY OF WASHING PLANT.

The capacity of a washing plant depends on the maximum flow of water through the washer and the percentage of clay held in suspension at the maximum viscosity at which precipitation of impurities is not retarded.

This maximum permissible viscosity will vary to some extent with clays from different deposits and can be determined only by close observation of a number of settling tests of slips of varying viscosities. In most cases a viscosity of about 1.094 will be the maximum. However, it is advisable to run at a viscosity a little lower than the maximum, a viscosity of 1.068 being safe practice.

The maximum amount of water that will flow through the ordinary rectangular washer, 10 feet long, 4 feet high, and 4 feet wide, without overflowing and produce maximum dispersion under given blunging conditions depends on the condition of the clay entering the washer, whether wet or dry, lumpy or disintegrated. Under the present-day conditions of kaolin refining, where the clay goes into the washer in large lumps, the maximum flow is about 1,200 cubic feet per hour.

It has been shown that a number of factors affect the percentage of clay contained in a slip of a given viscosity. Therefore these factors tend to increase or decrease the capacity of a washing plant, according to whether they decrease or increase the viscosity of the slip. For example, suppose the plant is operating under dry-weather conditions and maintaining a constant viscosity of 1.094; the slip will then contain 10.8 per cent of solids, but under wet-weather conditions the slip will contain only 7.4 per cent of clay, a decrease in capacity of 31 per cent, whereas if the clay has first been dried the slip will contain 16.2 per cent solids, an increase in capacity of 50 per cent over dry-weather conditions.

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FACTORS AFFECTING MINIMUM VISCOSITY.

As the previous tests showed that caustic soda produces the greatest dispersion in Georgia kaolin slip, it was used in commercial tests of kaolin refining, and it was found that not all of the factors affecting the initial viscosity had an effect on the degree of dispersion or the minimum viscosity produced by small additions of alkalies.

DEGREE OF BLUNGING.

It is seen upon comparing the curves of figure 4, plotted from tests made in dry weather, with those of figure 5, plotted from tests made in wet weather, that the degree of dispersion or minimum viscosity

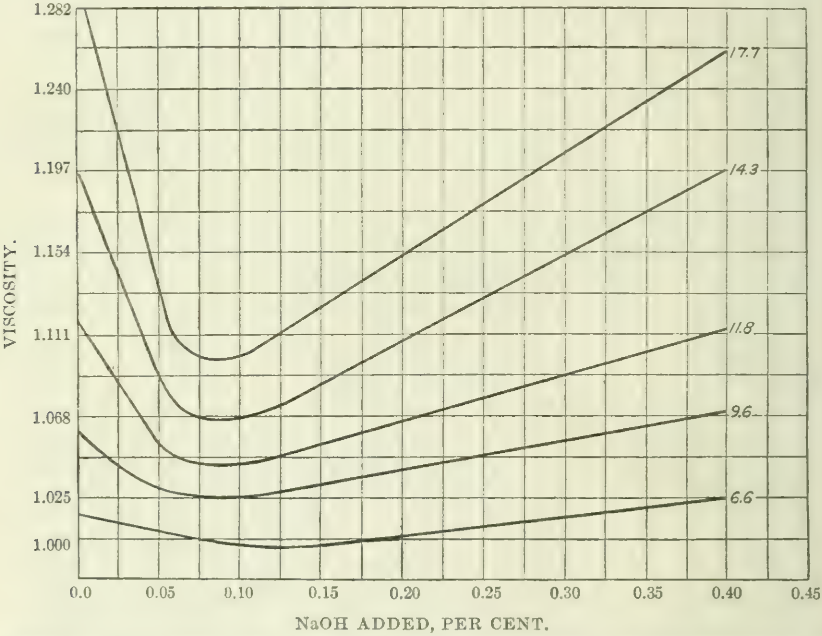


FIGURE 4.—Effect of caustic soda on viscosity of Georgia kaolin slips under dry-weather conditions. Figures on right show percentage of clay in slip.

of slips having the same clay content is the same, regardless of the wide difference in initial viscosity. For example: From the curve in figure 4, representing a slip which contained 9.6 per cent of clay, it is seen that the initial viscosity is 1.059 and the minimum 1.025, whereas the curve shown in figure 5, representing a slip containing 9.4 per cent solids, shows an initial viscosity of 1.145, but the same minimum of 1.025.

Comparison of results shown by the curves of figure 6, which were plotted from tests of slips blunged in a ball mill, with those of the curves shown in figure 4, indicates that similar conditions prevailed. Although there was a large drop in initial viscosity, the minimum

viscosity is the same for slips containing the same percentage of clay. Therefore the amount of blunging has no effect on the degree of dispersion or minimum viscosity of a slip of given clay content.

PREDRYING.

The curves shown in figure 7 were plotted from tests with slips of Georgia kaolin which had been previously dried to "bone dryness" on the top of steam pipes. By comparing these curves with those of figure 4, it is seen that predrying the clay decreases the initial viscosity—in slips containing less than 15 per cent clay—to that of the minimum viscosity. In other words, when the slip contains 15 per

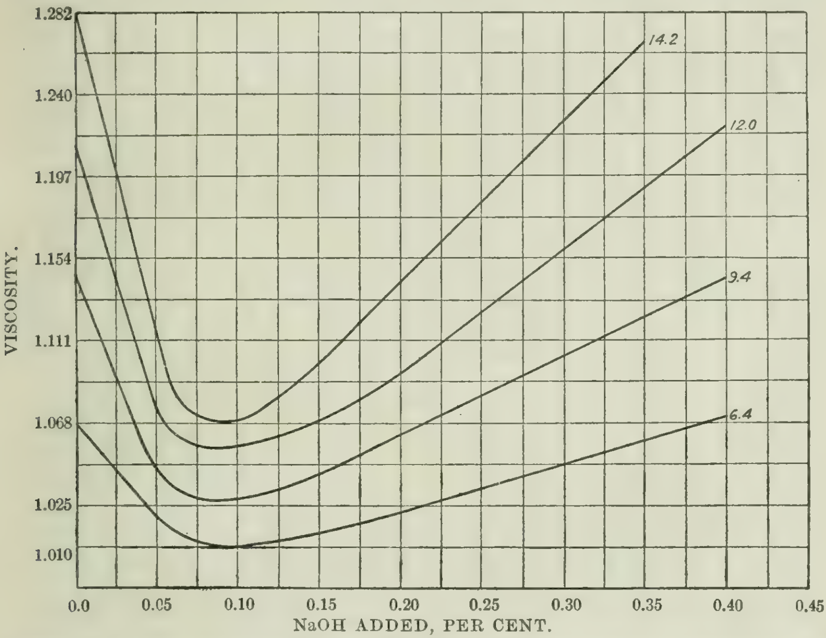


FIGURE 5.—Effect of caustic soda on viscosity of Georgia kaolin slips under wet-weather conditions. Figures on right show percentage of clay in slip.

cent or less of clay, predrying is just as effective in increasing dispersion as additions of caustic soda, but predrying is far more expensive than using the electrolyte. However, on adding caustic soda to such slips the viscosity is decreased still further, but the drop is very small.

As the minimum viscosity is not changed by the amount of blunging, and only slightly by severe predrying conditions, the capacity of a plant using a dispersing agent will be constant under such changing operating conditions.

USE OF ALUM.

The results of tests made with slips containing a small percentage (0.03 per cent) of alum are shown by the curves in figure 8. By comparing these curves with those of figure 4 it is seen that alum raises

the initial viscosity, increases the amount of caustic soda necessary to produce minimum viscosity, and decreases the degree of dispersion. Therefore the presence of a flocculating agent such as alum in the feed water is very objectionable to a successful application of the technical control of disperse systems in kaolin refining.

REFINING KAOLIN BY TECHNICAL CONTROL OF DISPERSE SYSTEM.

SEDIMENTATION PROCESS.

From laboratory experience and from suggestions made by Ashley, Bleininger, and others, it appears that the best method of utilizing

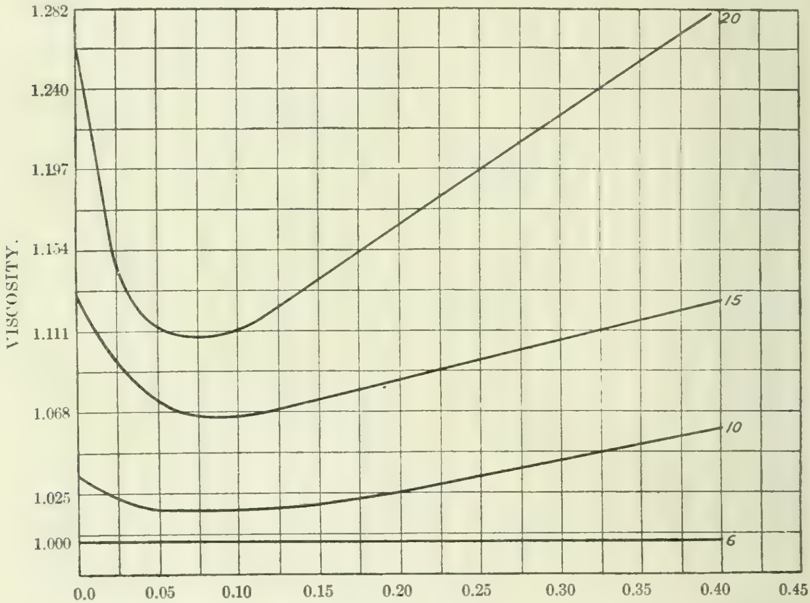


FIGURE 6.—Effect of caustic soda on viscosity of Georgia kaolin slips blunged in ball mill.

caustic soda as a deflocculating agent in kaolin refining is as follows: Sufficient caustic soda to cause maximum deflocculation or minimum viscosity is added to the clay and water in the washer. The deflocculated slip is run through the settling troughs, screened, and collected in the concentration tank, where it is allowed to stand long enough for the impurities to settle out. The slip is then siphoned into another tank and a flocculating agent added in order to coagulate the clay particles and concentrate the slip for filter pressing.

However, the results of a number of tests conducted in a small concrete tank 6 feet square and 2 feet deep showed that settling out the impurities in large tanks was not an economical process. The time required to settle out the impurities through a large quantity of slip was comparatively long, being about two hours, and in the

meantime much clay had also settled, which had to be thrown away with the impurities. Also several inches of slip had to be left in the bottom of the settling tank when the slip was drawn off to prevent some of the impure material being sucked up. Aside from the large loss of clay caused by use of such a method, the continuity of the refining process is stopped, which adds to the operating costs.

THE ELUTRIATION OR SLIMING PROCESS.

Experiments on settling out the impurities in troughs were next carried on. A new set of troughs was built for this purpose and after a number of changes in width and length of the last trough, good results were obtained. The elutriation process consists of 11 different

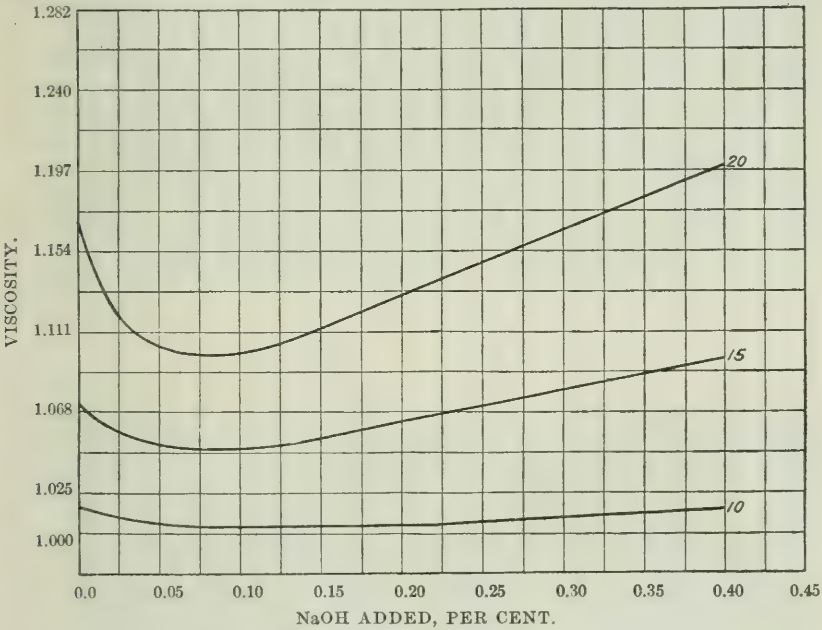


FIGURE 7.—Effect of caustic soda on Georgia kaolin slips made from predried clay.

operations which are as follows: (1) Storage and disintegration, (2) feeding, (3) blunging, (4) dispersion, (5) sliming, (6) coagulation, (7) screening, (8) concentration, (9) filter pressing, (10) drying, and (11) crushing.

STORAGE AND DISINTEGRATION.

The clay should be broken into lumps no larger than a man's fist and most of the clay should be much finer. In order to disintegrate the clay in this manner it is necessary to have a storage shed of at least 500-ton capacity, because during rainy weather the clay as mined from the pit is too sticky to be broken up.

All washing plants should have a storage shed for the crude clay regardless of the method of washing employed, for it has been shown

that the capacity of the plant will vary greatly with the condition of the clay entering the washer unless it is dispersed with an alkali. However, few kaolin refining plants have a storage shed; therefore the writer wishes to emphasize the fact that the first thing to be considered in constructing a washing plant, if constant conditions are to be maintained with resulting uniform product, is a well-constructed storage shed of sufficient capacity. The disintegrator should be of the centrifugal roll type, as this type works best with highly plastic clays.

FEEDING.

It has been shown that the quantity of caustic soda required to produce maximum dispersion depends upon the percentage of clay in the slip; therefore it is expedient to have a constant flow of clay

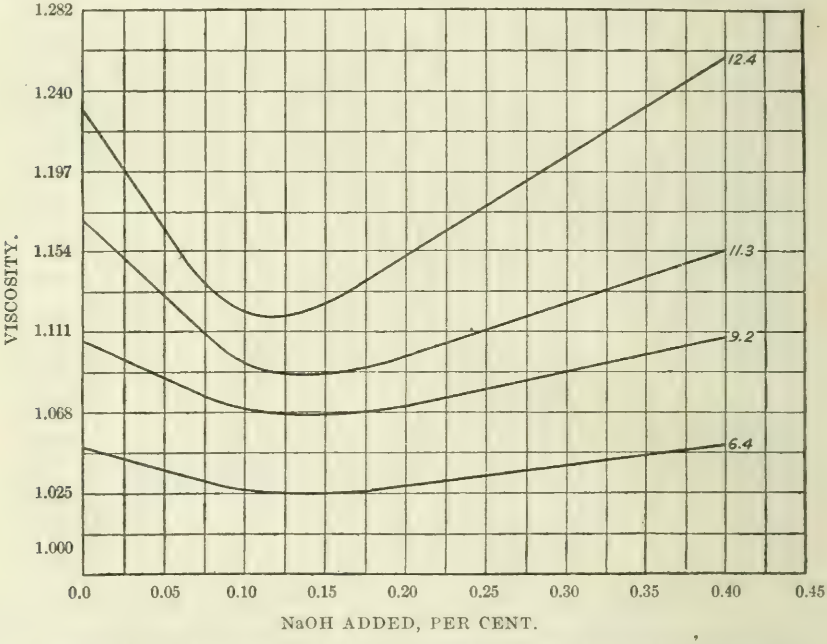


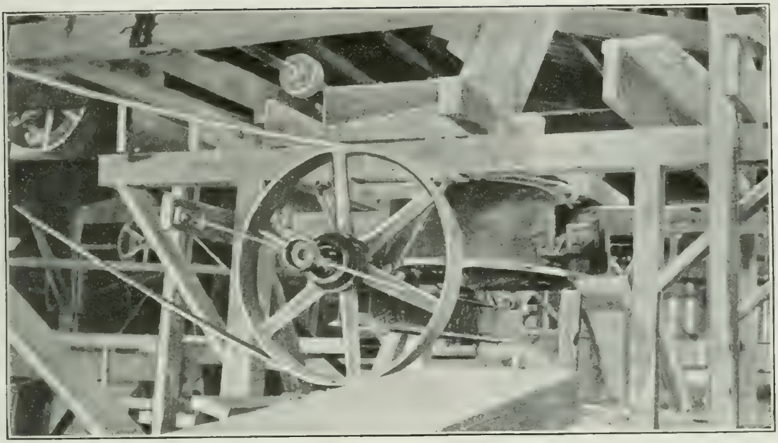
FIGURE 8.—Effect of caustic soda on Georgia kaolin slips containing 0.03 per cent of alum.

into the washer. The best way to obtain a constant flow is by the use of a clay feeder of the disk type. No feeder will deliver clay to a washer with any uniformity unless the clay has been previously crushed into small lumps; hence the necessity of using a disintegrator. One type of feeder is shown in Plate IV, *A*.

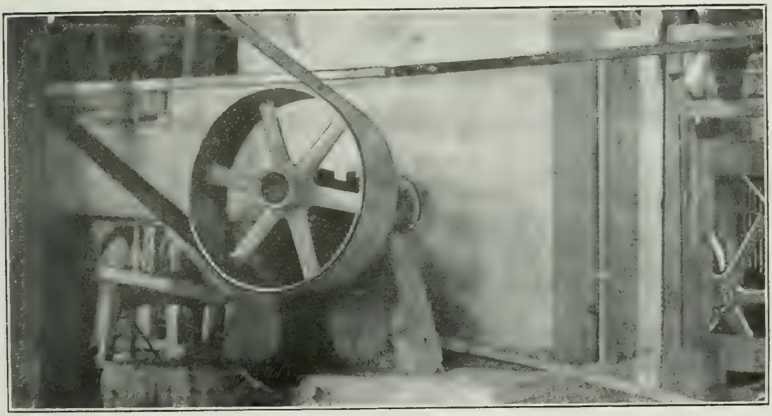
BLUNGING AND DISPERSION.

Blunging and dispersion will be discussed together as they are very closely related.

Blunging the clay, water, and alkali is one of the most important steps in the washing process, and too much emphasis can not be



A. DISK CLAY FEEDER.



B. CONCRETE WASHER OR BLUNGER.

laid upon this operation. Double blunging or washing is necessary to obtain complete dispersion and in the case of some very tough and tenacious clays that resist blunging it will be necessary to use three washers in order to get complete separation of the clay particles and impurities.

It is advisable to add the caustic soda to the slip in the second blunger, because if the flow of clay or water should be increased or decreased the clay content of the slip can be calculated from viscosity or specific-gravity tests of the slip leaving the first washer, and the flow of standard caustic-soda solution can be so regulated as to produce maximum dispersion under the changed flow of clay or water. In case the maximum permissible viscosity is exceeded the process should be stopped. In order that there will be no serious stoppage of the flow of clay or water into the washer there should be a storage bin of about 8-ton capacity, placed above the clay feeder, and the water fed into the washer by a No. 5 centrifugal pump. This pump should be set below the level of the bottom of a large concrete water-supply tank, about 30 by 15 by 8 feet, so that the water will run directly into the pump and prevent it from sucking air, which necessitates priming the pump.

TYPES OF WASHERS.

The rectangular washer used in nearly all washing plants has proved very successful in blunging the clay, but the power consumption has been very high, owing to faulty construction. The concrete washer illustrated in figure 9 and shown in operation in Plate IV, *B* will give efficient results, and the cost of repairs on this type of washer will be much lower than on the rectangular wooden box ordinarily used, as it can be easily relined without the necessity of rebuilding the whole washer.

ADDITION OF CAUSTIC SODA.

A standard solution of caustic soda is made up, and this solution is run into the second washer at a constant rate of about 10 cubic centimeters per second, which is obtained by allowing the solution to run through an efflux tube one-eighth of an inch in diameter. This efflux tube is placed about 2 inches from the bottom of the caustic soda supply tank so that it will not be easily clogged by any material that has settled to the bottom of the tank. The supply tank should also be equipped with two auxiliary efflux tubes of smaller diameter for regulating the quantity of caustic soda if the flow of clay is changed. The tank, which should have a capacity of 150 gallons, should be made from alkali-resisting material, such as enameled steel, and should contain an agitator. The head or top of the tank should be made air-tight in order that the effect of the varying

head due to the lowering of the level of the solution can be overcome by the application of Mariotte's principle of the flow of liquid from an immersed tube, a constant flow of standard solution into the washer being thus obtained.

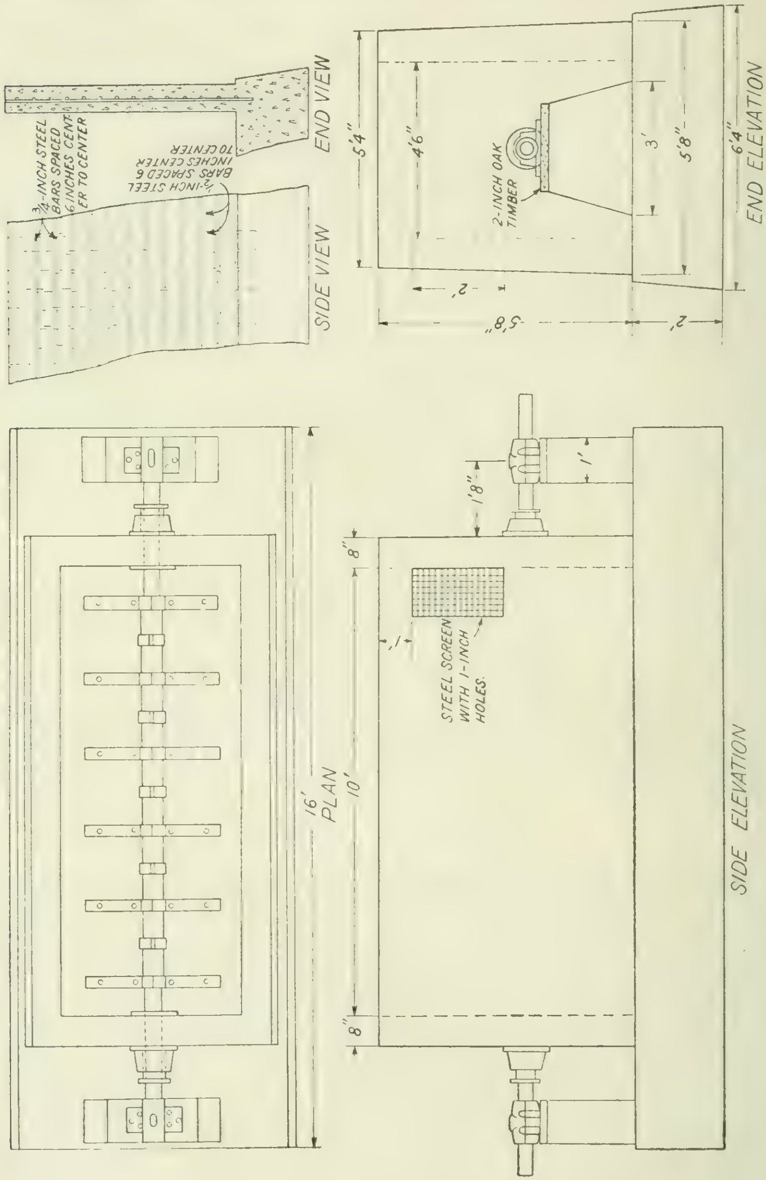


FIGURE 9.—Design of concrete washer.

The figures given above for the rate of flow of standard caustic soda solution and for the size of the main efflux tube are somewhat arbitrary and can be changed to suit different conditions.

STRENGTH OF CAUSTIC-SODA SOLUTION

The proper strength of caustic soda solution to use will depend on the rate at which the solution is allowed to flow into the washer and the rate at which the clay is fed to the washer. For example, if 5 tons of clay is being fed to the washer every hour, then $5 \times 2000 \times 0.00075$, or 7.5, pounds, of caustic soda will have to be added every hour to produce complete dispersion. Now, if the rate of flow of the solution is 10 cubic centimeters per second, every cubic centimeter of standard solution will have to contain $\frac{7.5 \times 454.5}{3600 \times 10} = 0.094$ gram of caustic soda.

Therefore the normal solution is $\frac{0.094 \times 1000}{40} N = 2.35N$.

SLIMING.

After thorough blunging and complete dispersion the slip is run through the elutriation troughs. The troughs used by the writer with good success do not differ from the ordinary mica troughs used at present in most washing plants, except that a long fan-shaped trough is added at the end of the series of troughs.

This trough should be at least 125 feet long, 2 feet wide at the inlet, and the width at the discharge end should be such as to produce a depth of slip of not over 1 inch. The trough should be constructed with great care, for the bottom must be perfectly level both lengthwise and crosswise and the sides very smooth, as too great a frictional resistance to the flow causes coagulation of the slip along the sides and results in faster flow through the center of the trough. The bottom of the trough should be rough and uniform in texture, because on a smooth bottom the slip tends to roll the impurities along, and on an uneven bottom the slip tends to thicken around the spots of most resistance, causing it to flow too fast in other parts of the trough. The best material of which to construct these troughs is concrete, and by proper sizing of the aggregate and proper troweling the required surfaces can be obtained.

There will be less tendency for the clay particles to coagulate around spots of greater resistance if the slip is agitated before it enters the last trough. This can be easily done by having the fan-shaped trough lower than the others and then running the slip over riffles as it passes from the narrow troughs into the fan-shaped one. (See fig. 10.)

COAGULATION.

As the slip comes from the troughs it is still in a state of maximum deflocculation and therefore can not be concentrated as the exceedingly fine particles would not settle even after weeks of standing.

Furthermore, any attempts at filter-pressing the slip as it comes from the sliming troughs would be futile for, aside from the fact that the quantity of water to be removed would be so great that the process would not be practicable, the alkaline condition of the slip with the resulting dispersion of the clay particles would make filter-pressing almost impossible, as the exceedingly fine particles would tend to

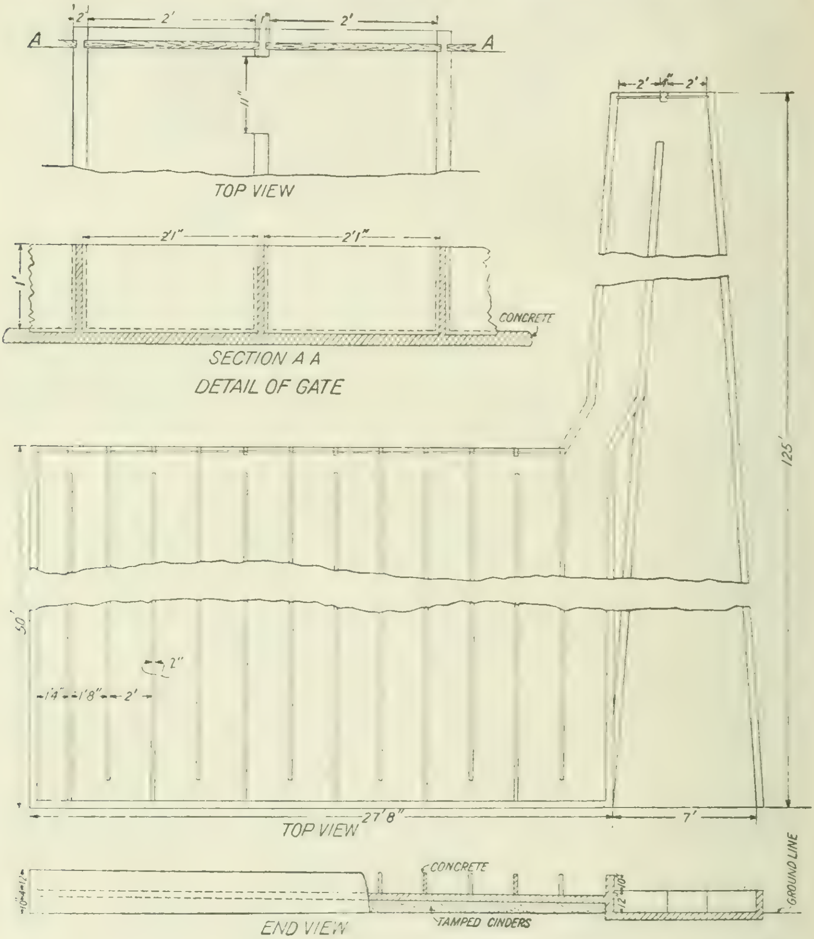


FIGURE 10.—Design of floating troughs.

clog the filter cloth and what water did run through would be very turbid. Therefore it is necessary to add some flocculating or coagulating agent. Alum is usually used for this purpose, but in case the washing plant is using the water from the concentration tanks and filter presses over and over again alum can not be used, as a very small proportion (0.02 per cent or less) in the feed water decreases the effect of caustic soda and consequently increases the amount of soda

necessary to cause maximum dispersion. If just enough sulphuric acid is added to neutralize the caustic soda, the slip is brought back to its normal state.

The sulphuric acid solution should be the same strength as the caustic soda solution, and it should be added to the slip in the same manner. Under these conditions perfect neutralization will result and there will not be an excess of caustic soda left to cause trouble in settling and filter-pressing or an excess of sulphuric acid left to cause trouble in blunging and dispersion. The sulphuric acid solution is added to the slip at the point where it leaves the sliming troughs. After the addition of the acid the slip is run through a long narrow trough, say 50 feet by 1 foot by 2 feet, containing a number of riffles for mixing the acid solution with the alkaline slip. The bottom of this trough should have a drop of at least 1 foot in 50 in order to cause a rapid flow.

SCREENING.

After the slip is neutralized by adding sulphuric acid it is advisable to run it through a rotary screen of about 120 mesh. This screen will remove any chips of wood or other foreign materials that float on the top of the slip; it also acts as an agitator in case some of the alkaline slip has not been completely neutralized. Care should be taken that practically all of the acid has combined with the caustic soda before reaching the screen, as any excess of acid will act upon the screen cloth and shorten its life.

CONCENTRATION.

The concentration of the slip is best accomplished by running the neutral slip into large concrete tanks (see fig. 11) 60 feet long, 30 feet wide, and 6 feet deep, where it is allowed to stand long enough for the clay to precipitate; then the supernatant liquid is drawn off, the time of settling governing the thickness of the slip. However, after about 96 hours the amount of precipitation is exceedingly small and in general 72 hours is sufficient for the concentration of the slip. This concentrated slip is then run into a small retaining tank, or, better still, is pumped into the filter presses direct from the concentration tanks.

FILTER-PRESSING.

Under present conditions of kaolin refining the filter-pressing of the thickened clay slip has given more trouble than all the rest of the washing operations. The troubles have been numerous and varied, and have been partly due to the type of filter press used, poor or clogged filter cloth, too thin a slip, condition of clay particles, whether dispersed or coagulated, and other factors. In view of these facts

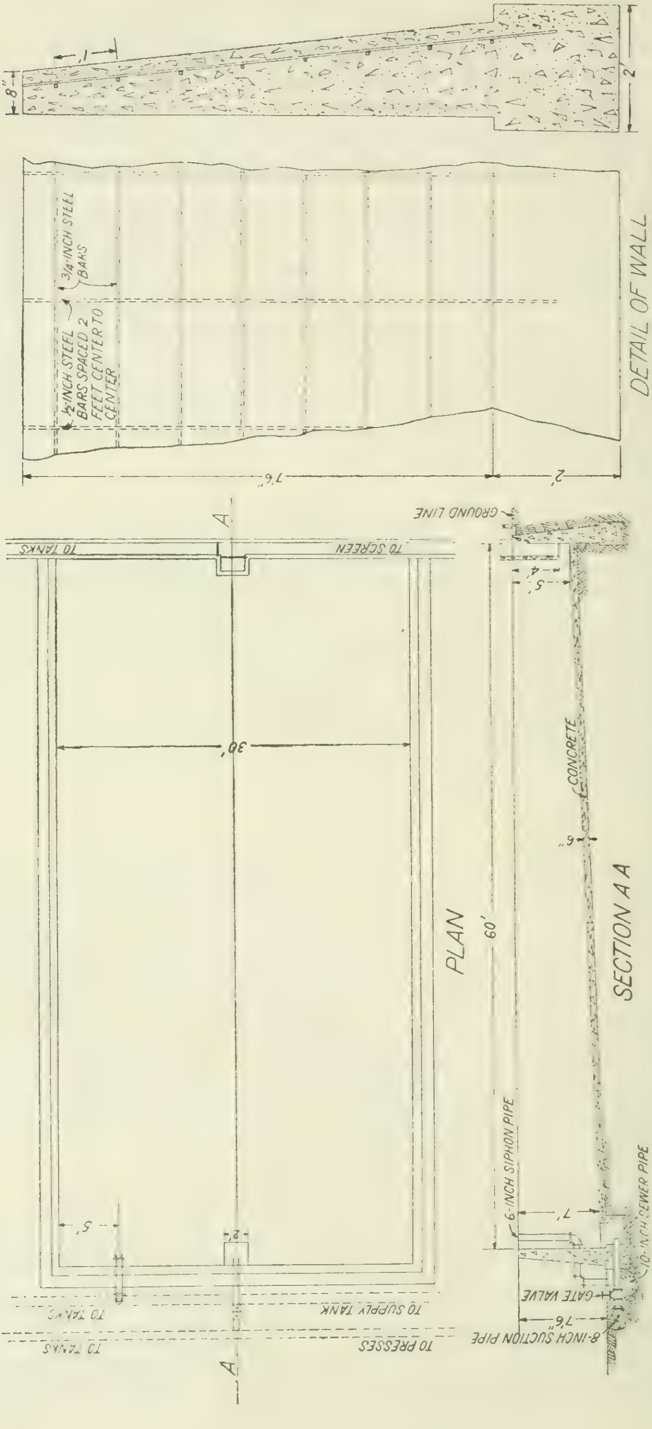


FIGURE 11.—Design of concentration tank.

numerous attempts have been made to devise other methods of drying the clay, but to the writer's knowledge none has proved more efficient than the filter press. The osmose purification process used in England [a] eliminates the filter press, but it is doubtful whether the apparatus would meet conditions in this country.

Bleininger [b] says:

> If the electrical continuous separation can replace the filter press economically its use would be justified. To a large extent it would be a matter of the comparative economy of the electrical endosmose apparatus and the filter press. If the latter should be improved, as has been done in the so-called clamshell press, it is quite possible that the economic advantage might remain with the filter press.

One of the chief sources of trouble in filter-pressing highly plastic clay slips is a slip that has not been sufficiently concentrated. In other words, the clay has not been allowed time to settle, owing, perhaps, to lack of tank capacity. The slip for filter-pressing should contain at least 30 per cent of clay. It must be remembered that in order to force this thick clay slip into the presses the pumps must be below the bottom of the tank from which they are drawing the slip; as the ordinary filter-press pump will not successfully lift a thick clay slip.

DRYING.

The drying of the filter-press cakes is best accomplished in a tunnel drier heated by exhaust or live steam. During the summer months open-air driers can be used to good advantage.

CRUSHING.

The filter-press cakes after being thoroughly dried are crushed into small pieces in a set of rolls.

LAYOUT OF PLANT.

The plan of a washing plant equipped for using the chemical process is shown in Plate V.

COST OF THE CAUSTIC SODA AND SULPHURIC ACID TREATMENT.

The extra cost over present-day methods of the caustic soda and sulphuric acid refining of kaolins may be divided into three factors: (1) First cost, maintenance, and operation of extra mechanical equipment required; (2) cost of chemicals; (3) chemist's salary. These costs, on the basis of 50 tons of clay treated per day, follow.

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[a] Ormandy, W. R., British clays under the osmose purification process: Trans. Eng. Cer. Soc., vol. 13, 1913-1914, pp. 35-48.

[b] Bleininger, A. V., Use of sodium salts in purification of clays and in the casting process: Tech. Paper 51, Bureau of Standards, Sept. 25, 1915, p. 19.

MECHANICAL EQUIPMENT.

The extra equipment necessary for the successful operation of the process is: One disk clay feeder, one washer, extra settling trough, and two 200-gallon tanks. The cost of operating and maintaining this extra equipment will be about $0.12 per ton of clay treated.

CHEMICALS.

With caustic soda at $0.03 per pound and sulphuric acid $0.025 per pound, the cost of chemicals will be $0.0825 per ton of clay.

CHEMIST.

Successful operation will depend upon careful technical control of every step of the process. It will therefore be necessary to have a trained chemist available at all times. The services of such a chemist will approximate $0.15 a ton.

The extra total cost will therefore be about $0.35 a ton. However, it must be remembered in comparing the cost of the new with the old method that the caustic soda and sulphuric acid process increases the capacity of the plant. For example, slip with a maximum permissible viscosity of 1.094 contains after complete dispersion 17 per cent of clay, whereas the slip that is not dispersed contains 10.8 per cent during dry weather and 7.6 per cent during wet weather. As the average percentage of clay content, under the present-day methods, is 7.64 per cent, the increase in capacity will be 123 per cent, which will more than offset the increased cost of operation.

CONCLUSIONS DRAWN FROM RESULTS OF TESTS.

The application of the new process of treatment to kaolin refining on a commercial scale is thoroughly practical and the product has a purity impossible to attain under present methods of refining. In order to utilize the caustic soda sulphuric acid process with clay such as that experimented with it must be remembered that:

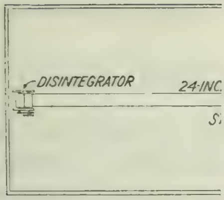
1. The clay and water must be fed into the washer at a uniform rate.

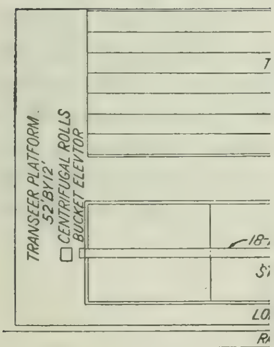
2. Double blunging or washing is necessary. Without thorough blunging the process is doomed to failure.

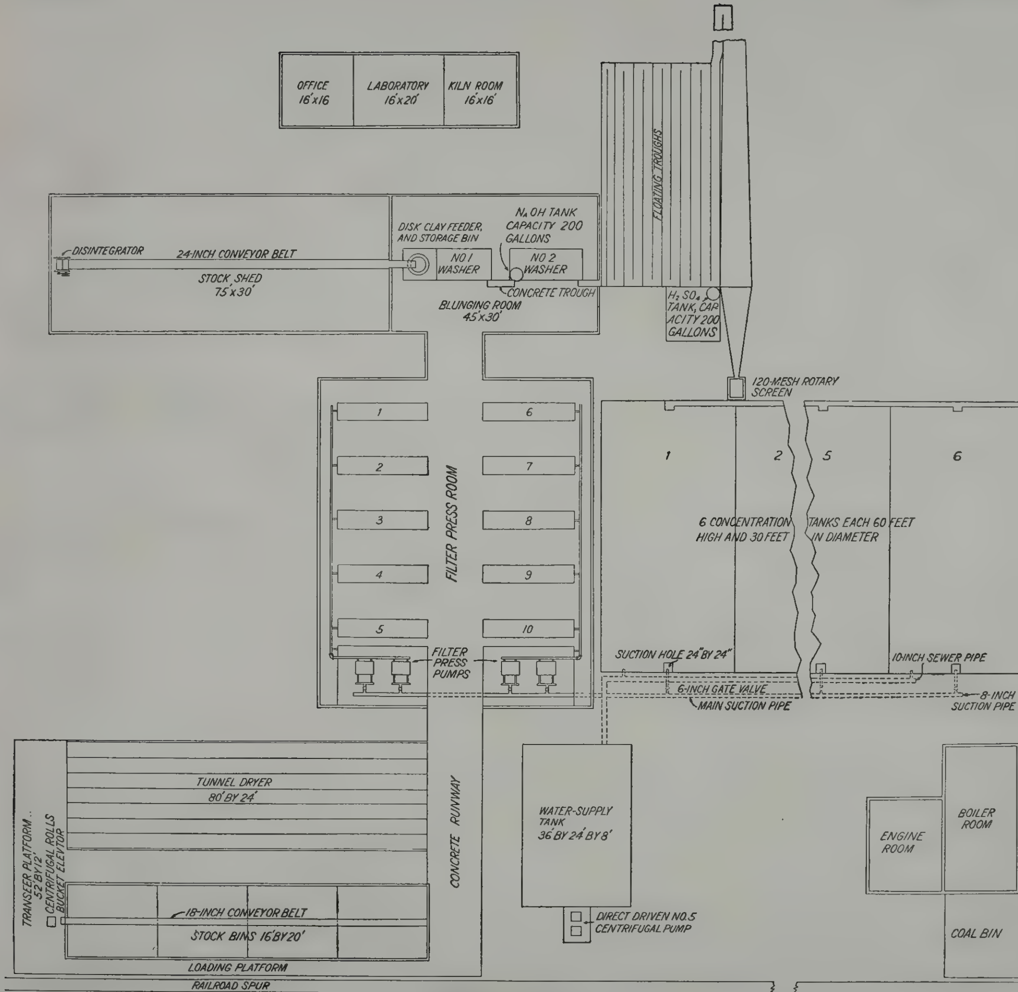
3. The caustic soda must be added in definite quantities, the amount depending upon the character of the clay and the quantity being fed to the washer.

4. A constant viscosity of about 1.068 must be maintained at the head of the sliming troughs in order to obtain a uniform product. The viscosity should never exceed 1.094.

5. It is advisable to agitate the slip before it is allowed to run through the fan-shaped trough.


DISINTEGRATOR
24-INC


TRANSEER PLATFORM
52' BY 12'
CENTRIFUGAL ROLLS
BUCKET ELEVTOR



PLAN OF WASHING PLANT.

6. The last sliming or settling trough should be fan-shaped, at least 125 feet long, 2 feet wide at the inlet, 7 feet wide at the discharge end, and perfectly level both lengthwise and crosswise. The sides of this trough should be very smooth; the bottom should be comparatively rough but uniform in texture.

7. Sufficient sulphuric acid to neutralize the caustic soda should be added, and no more.

8. It is absolutely necessary to have a chemist, one familiar with clay disperse systems, present at all times, for it is impossible to make the process fool-proof.

UTILIZATION OF REFINED GEORGIA KAOLIN.

After an improved process of kaolin refining has been worked out, the question, "Will the treated clay be sufficiently improved so that it can be utilized in the manufacture of the finer grades of ceramic wares by substituting it for the English china clay?" at once arises. In order to answer this question several tons of clay was refined by the new process at the plant of the Georgia Kaolin Co., to be used for test purposes. Owing to the fact that during the refining of this clay the flow of clay into the washer was not uniform because a clay feeder had not been installed and the amount of clay had to be approximately determined by viscosity tests taken every five minutes, it was not as pure as would be obtainable under standard conditions. However, on making a number of settling tests it was thought that sufficient improvement had been made to warrant some preliminary tests of the burned color of the clay.

PRELIMINARY TESTS TO DETERMINE PHYSICAL PROPERTIES AND COLOR.

SHRINKAGE.

The average linear shrinkage of the washed Georgia, treated Georgia, and English china clays are given in the table following. The shrinkage was determined by measuring the dry length and burned length of a 5-centimeter mark placed upon 10-centimeter disks in the green state. These disks were made by pressing the plastic clay into plaster molds. The disks were dried at 110° C. and the dry lengths measured, then fired in saggers at cone 10 in the kilns of the Mayer China Co., and the burning shrinkage determined.

Drying shrinkage and burning shrinkage of kaolin disks.

Kaolins tested.	Drying shrinkage, per cent.	Burning shrinkage, per cent.
English china clay	2.32	4.48
Washed Georgia kaolin	4.38	8.12
Treated Georgia kaolin	3.24	8.16

The table shows that the new process decreases the drying shrinkage about 25 per cent, but the burning shrinkage is about the same.

COLOR IN WHITE-WARE BODIES.

Some preliminary tests on the use of the treated Georgia kaolin in white-ware bodies were made in the ceramic laboratories of the Ohio State University, Columbus, Ohio. The purpose of these tests was to determine how much improvement in burning color the treated clay would show over that of the washed Georgia kaolin when made into glazed white-ware bodies, and also the approximate percentage of treated Georgia clay that could be substituted for the English china clay in a white-ware body without impairing the color of the glazed body.

MATERIALS USED IN MAKING BODIES.

The commercial materials used in this investigation were as follows:

Feldspar.—Canadian feldspar, Pennsylvania Feldspar Co.

Flint.—Pulverized quartz sand, Ohio Silica Co.

Florida kaolin.—Edgar Plastic Kaolin Co.

English china clay.—Moore & Munger's M. W. M. No. 1.

Ball clay.—Tennessee No. 9, Johnson & Porter Co.

Washed Georgia kaolin.—Georgia Kaolin Co.

Treated Georgia kaolin.—Georgia Kaolin Co.

Whiting.—Gilders.

The analyses of these materials are given in Table 3 following:

TABLE 3.—*Results of analyses of materials used in tests.*

Constituent.	Feldspar.	Flint.	Florida kaolin.	English china clay.	Ball Clay.	Washed Georgia kaolin.[a]	Whiting.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	65.15	99.18	45.50	47.37	51.20	45.53	1.30
Alumina (Al_2O_3)	18.65	.20	39.30	37.85	32.10	37.97	2.14
Iron oxide (Fe_2O_3)	.10	.06	.05	.31	.73	.73	.10
Titanium oxide (TiO_2)	.00	.01	.00	.04	1.40	1.55	.00
Lime (CaO)	.18	.01	.00	.00	.13	.05	54.40
Magnesia (MgO)	.00	.01	Trace.	Trace.	.00	.13	.00
Potash (K_2O)	10.36	....	.42	1.40	.69	....	.00
Soda (Na_2O)	4.31	....	.44	.14	.10	....	.00
Ignition loss	.32	.11	14.20	12.60	13.75	13.69	.00
Carbon dioxide	.00	.00	.00	.00	.00	....	42.68
Total	99.87	99.58	99.91	99.71	100.10	99.65	100.62

[a] The treated Georgia kaolin was not analyzed.

COMPOSITION OF THE BODIES USED.

The composition of the seven bodies that were compounded from the above white-burning materials is given in Table 4.

TABLE 4.—*Composition of bodies used.*

Material.	Proportion used in body No.—						
	1	2	3	4	5	6	7
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Feldspar	15	15	15	15	15	15	15
Flint	38	38	38	38	38	38	38
Florida kaolin	7	7	7	7	7	7	7
Tennessee ball clay	3	3	3	3	3	3	3
Whiting	2	2	2	2	2	2	2
English china clay	35	23	12	0	23	12	0
Washed Georgia kaolin	0	12	23	35	0	0	0
Treated Georgia kaolin	0	0	0	0	12	23	35
	100	100	100	100	100	100	100

PREPARATION OF THE BODIES.

The materials for each body, consisting of 8,000 grams, were weighed out and the total weight checked by weighing the batch. Each body was ground wet for five hours in a porcelain-lined ball mill, sieved through a 120-mesh screen, and divided into two parts, one part being used for casting small cups, and the other part being dried to a plastic state in plaster molds lined with cheesecloth, and after the clay had been wedged small pots like flower pots were made from it on a jigger.

PREPARATION OF TEST PIECES.

The bodies were made up into 48 test pieces each—24 by casting and 24 by molding on a jigger. These test pieces were first air-dried and then the drying was completed in a gas-fired drier.

BISCUIT BURN.

In order that the range of vitrification of the test pieces would cover the range of vitrification of commercial white-ware bodies, from the high porosity of wall tile to the low porosity of vitreous china, one half of the pieces were biscuit burned at cone 4 and the other half at cone 11.

GLOSS BURN.

All pieces were gloss fired at cone 3. The glaze and frit used had the following molecular formula:

Molecular composition of glaze.

$$\left.\begin{array}{l} 0.25\ PbO \\ 0.15\ K_2O \\ 0.05\ Na_2O \\ 0.45\ CaO \\ 0.10\ ZrO_2 \end{array}\right\} 0.25\ Al_2O_3 \left\{\begin{array}{l} 2.0\ SiO_2 \\ 0.4\ B_2O_3 \end{array}\right.$$

Molecular composition of frit.

$$\left.\begin{array}{l} 0.10\ Na_2O \\ 0.90\ CaO \end{array}\right\} 0.1\ Al_2O_3 \left\{\begin{array}{l} 2.0\ SiO_2 \\ 0.4\ B_2O_3 \end{array}\right.$$

The glaze was applied in a thick coat to one half of the trials by dipping and in a thin coat to the other half by spraying.

RESULTS OF TESTS.

TEST PIECES BISCUIT-FIRED AT CONE 12 AND GLOSS-FIRED AT CONE 3.

No black specks were observed in bodies 5, 6, and 7, containing treated Georgia kaolin, whereas a number of specks appeared in bodies 2, 3, and 4, especially in body 4, which contained 35 per cent of washed Georgia kaolin. The treated Georgia kaolin bodies had a better color than the washed kaolin. Body 5 had just as good a color as body 1, which contained English china clay, while body 6 had a slight creamy tinge and body 7 a decided cream color, when compared with body 1.

TEST PIECES BISCUIT-FIRED AT CONE 4 AND GLOSS-FIRED AT CONE 3.

A few black specks showed in body 4, but the difference in color between the treated and washed kaolin bodies was only slight at this heat treatment. Bodies 5 and 6 had just as good color as body 1, but body 7 showed a very slight creamy color when compared with 1.

CONCLUSIONS AS TO RESULTS OF COLOR TESTS.

Glazed white-ware bodies containing the treated Georgia kaolin have a whiter color than those containing the washed Georgia kaolin.

Treated Georgia kaolin can be substituted for at least 40 per cent of the English china clay in vitreous china, and for all the English china clay in wall-tile bodies without affecting the color of the product.

TESTS IN MAKING VITREOUS CHINA.

These preliminary tests gave indications of the possible commercial uses of the treated Georgia clay and justified further tests of substituting it for English china clay. In order that the tests might be made under commercial conditions of white-ware manufacture, they were conducted at the plants of the Beaver Falls Art Tile Co., the Mayer China Co., and the Mosaic Tile Co., through the courtesy of these firms.

The commercial tests of the use of treated Georgia kaolin as a substitute for English china clay in vitreous china bodies were made at the Mayer China Co. plant at Beaver Falls, Pa. The main object of these tests was to determine whether a practicable vitreous china body composed entirely of American materials could be made.

PROCEDURE IN TESTS.

MATERIALS USED.

The materials used in this investigation, with the exception of the treated Georgia kaolin, were taken from the stock bins of the china company. The following materials were used:

Feldspar.—Eureka Flint & Spar Co.

Flint.—Ohio Silica Co.

Florida kaolin.—Edgar Plastic Kaolin Co.

English china clay.—Moore & Munger's M. G. R. No. 2.

Ball clay.—Moore & Munger's English ball clay.

Treated Georgia kaolin.—Georgia Kaolin Co.

COMPOSITION OF BODIES.

The percentage composition of each body used in the three series of tests comprising this investigation are given in Table 5 following:

TABLE 5.—*Composition and physical properties of bodies used in tests.*

COMPOSITION.

Item.	Series A, body No.—						Series B, body No.—				Series C, body No.					
	20	21	22	23	24	25	26	27	28	29	29b	30	31	32	33	34
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Feldspar	16.0	16.0	16.0	16.0	16.0	16.0	17.0	18.0	16.0	16.0	16.0	16.0	16.0	16.0	17.0	16.0
Flint	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
Ball clay	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	3.5	....	....	....	....
Florida kaolin	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
English china clay	29.0	24.2	20.3	18.4	14.5	18.4	16.0	15.0	14.5	13.5	13.5	17.5	19.5	17.5	13.5	19.5
Treated Georgia kaolin	....	5.8	8.7	10.6	14.5	....	12.0	12.0	13.5	13.5	13.5	13.5	15.0	17.0	20.0	15.0
Washed Georgia kaolin	....	....	....	....	....	10.6	....	....	....	....	....	....	....	....	....	....
Whiting	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	4.0	4.0	4.0	4.0	3.0	2.0	2.0
Magnesite	....	....	....	....	....	....	....	....	....	....	....	....	....	1.0	2.0	2.0

PHYSICAL PROPERTIES.

Item.	20	21	22	23	24	25	26	27	28	29	29b	30	31	32	33	34
Total shrinkage	11.46	12.00	12.30	12.54	12.78	12.74	12.60	12.96	12.64	13.34	12.70	12.06	11.34	13.60	13.40	12.84
Drying shrinkage	2.42	2.60	2.78	3.00	3.17	3.16	2.84	3.00	3.20	3.16	3.08	2.24	2.50	3.14	3.22	2.58
Burning shrinkage	9.06	9.40	9.52	9.54	9.61	9.58	9.76	9.96	9.44	10.18	9.72	9.82	8.84	10.46	10.18	10.26
Absorption	0.05	0.41	1.00	1.08	1.30	1.02	0.26	0.03	0.60	0.02	0.16	1.19	2.26	1.05	0.76	1.04
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
Translucency	0.65	....	....	....	....	....	0.61	0.64	0.61	0.68	0.40	0.45	0.46	0.51	0.53	0.54

PREPARATION OF BODIES.

The weight of each ingredient taken was determined from the percentage composition, figured on the basis of an 8,000-gram batch for each body. After weighing and checking the total weight by weighing the batch 1.2 grams of cobalt sulphate was added for a stain, and the bodies blunged in the ordinary wet way in porcelain-lined ball mills. The bodies in series A were ground for only five hours, but after the bodies of this series were biscuited it was found that the blunging was insufficient to give the desired uniform texture to each body; therefore the bodies of series B and C were blunged for 20 hours. After thorough grinding, the bodies were passed through a 120-mesh sieve and dried to a plastic condition in plaster molds lined with cheesecloth. As soon as the bodies were sufficiently dry they were wedged on a marble slab, and then each body was made up into 10 disks 10 centimeters in diameter for shrinkage and absorption tests, and twelve 5-inch plates for color comparisons. Twenty-four wedge-shaped pieces for translucency tests were also made from each body of series B and C. These pieces were allowed to dry for about 12 hours and then fettled.

BISCUIT BURN.

The finished pieces were placed in saggers in the ordinary commercial way, and placed in the second ring of the biscuit kiln. The pieces in series A and B were burned to cone 10, but those in series C were burned only to cone 9, owing to the lower temperature in the kiln in which the test pieces of this series were burned.

GLAZING.

The glaze and frit used had the following molecular formula:

Molecular composition of glaze.

$$\left.\begin{array}{l} 0.058\ K_2O \\ 0.207\ Na_2O \\ 0.530\ CaO \\ 0.205\ PbO \end{array}\right\} 0.275\ Al_2O_3 \left\{\begin{array}{l} 2.540\ SiO_2 \\ 0.414\ B_2O_3 \end{array}\right.$$

Molecular composition of frit.

$$\left.\begin{array}{l} 0.272\ Na_2O \\ 0.031\ K_2O \\ 0.697\ CaO \end{array}\right\} 0.272\ Al_2O_3 \left\{\begin{array}{l} 2.550\ SiO_2 \\ 0.544\ B_2O_3 \end{array}\right.$$

Eight kilograms of the above glaze was ground in the ordinary wet way for 60 hours in a porcelain-lined ball mill, passed through a 120-mesh sieve, and flocculated or thickened by the addition of 0.13 per cent $CaCl_2$, calculated on the basis of dry weight. The thickened glaze was then applied to the biscuited plates by dipping in the ordinary commercial way.

GLOSS BURN.

The glazed pieces were gloss fired at cone 1 in the gloss kilns of the company.

RESULTS OF TESTS.

The physical and pyrophysical properties of the different bodies shown in Table 5 were compared with those of body 20, which was represented to the writer by Mr. Ernest Mayer as being a practicable vitreous china body. The physical and pyrophysical properties studied were as follows: Working properties, drying shrinkage, burning shrinkage, absorption, transluscency, and color.

The working properties of the bodies were studied as regards the ease which the ware was formed in the jigger without flawing.

The drying shrinkage and total shrinkage were determined by measuring the dry and burned lengths of 5-centimeter marks placed on the 10-centimeter disks while in the green state. The drying and total-shrinkage data given in Table 5 are expressed in percentage of green length. The burning shrinkage was calculated by subtracting the percentage of drying shrinkage from the percentage of total shrinkage.

The absorption data were obtained by weighing the dry disks and then soaking them in distilled water for 48 hours and again weighing. The average absorptions given in Table 5 are expressed in percentages of dry weight.

The translucency was determined by measuring the thickest part of the wedge-shaped piece through which light would pass. The average translucencies are given in centimeters in Table 5.

SERIES A TESTS.

The purpose of the tests in series A was to study the direct substitution of treated Georgia kaolin for English china clay in a practical vitreous china body

CONCLUSIONS FROM RESULTS OF SERIES A.

As the proportion of treated Georgia clay was increased the working properties of the body were improved, the drying and burning shrinkages and the absorption were increased. This decreased vitrification of the Georgia-kaolin bodies is not due to the difference in fineness of grain of the English and Georgia clays, as is commonly thought, for the Georgia kaolin is much finer grained than the English china clay, but is probably due to the low alkali content of the Georgia kaolins.

The colors of bodies 21, 22, and 23 were just as good as that of body 20, whereas body 24 showed a slight cream color, therefore only

about 50 per cent of the English china clay in an ordinary vitreous china body can be replaced by this treated Georgia kaolin before the color of the glazed product is impaired.

SERIES B TESTS.

The tests in series B were designed to obtain a body of low absorption and still containing the maximum percentage of treated Georgia kaolin. For this purpose the feldspar content in bodies 26 and 27, and the whiting content in bodies 28 and 29 were increased.

CONCLUSIONS FROM RESULTS OF SERIES B.

The working properties of the four bodies of this series were very good. The burning shrinkage was increased, with resulting decreased absorption and increased translucency. The color of all the bodies of this series was just as good as that of body 20. Body 29 was a good vitreous china body of high translucency.

SERIES C TESTS.

The purpose of the tests of series C was to study the effect of substituting treated Georgia kaolin for ball clay, and magnesite for part of the whiting. Owing to the decreased biscuit heat the bodies of this series had an abnormally high absorption and low translucency, as may be seen by comparing the data for bodies 29 and 29b, Table 6. These two bodies had the same composition but were biscuit-burned with different heat treatments.

CONCLUSIONS FROM RESULTS OF SERIES C.

Substituting treated Georgia for ball clay decreased the drying and burning shrinkage and increased the absorption. The translucency was increased regardless of the decrease in vitrification.

Magnesite had a greater fluxing action than whiting, as is seen by comparing the absorption of body 31 with that of 34.

A direct substitution of Georgia clay for ball clay made the body too short, and therefore greater amounts of Georgia kaolin must be used, as compared with ball clay, to produce a practicable vitreous china body. Bodies 32 and 33, containing 17 per cent and 20 per cent of Georgia kaolin, respectively, had good plasticity, and worked well in the jigger, whereas bodies 30 and 31, which contained 13.5 and 15 per cent, were too short.

Bodies 31, 32, 33, and 34 of series C had a much better color than bodies 20 and 29 of series B, which contained ball clay. Bodies 33 and 34 had the best color of those in series C, which was evidently due to the substitution of magnesite for 50 per cent of the whiting.

GENERAL CONCLUSIONS AS TO PRACTICABILITY OF MAKING CHINA FROM GEORGIA CLAYS.

A commercial vitreous china body could not be obtained by the direct substitution of refined Georgia kaolin for English china clay, but the fluxes had to be increased to obtain the desired degree of vitrification.

The substitution of treated Georgia kaolin for all the ball clay and 50 per cent of the English china clay produced a body (No. 33) of good working qualities and as good a color as the whitest commercial ware and of a far better color than most vitreous chinaware on the market.

Body 33 contained 8 per cent of Florida kaolin, 13.5 per cent of English china clay, and 20 per cent of treated Georgia kaolin. As far as color is concerned, more than 20 per cent of treated Georgia kaolin can be used in bodies containing no ball clay, but the writer is of the opinion that if more than 20 per cent were added the temperature of the biscuit heat would have to be increased in order to obtain the desired vitrification, as an increase in percentage of fluxes over that in body 33 would reduce the toughness of the ware. As toughness is an important factor in high-grade vitreous china or hotel china, 20 per cent of treated Georgia kaolin is about the maximum proportion that can be used in this class of ware. In order to produce a vitreous china body containing only American clays it would be necessary in a body such as No. 33 to substitute for the 13.5 per cent of English china clay a domestic kaolin that is as easily vitrified as the English china clay and having as good a burning color.

MANUFACTURE OF WALL TILE.

The commercial tests of the substitution of treated Georgia clay for English china clay in wall tile were made at the factories of the Beaver Falls Art Tile Co., Beaver Falls, Pa., and the Mosaic Tile Co., Zanesville, Ohio. As the tests at the Beaver Falls plant were of a preliminary nature they will be discussed first.

PRELIMINARY TESTS.

The purpose of the preliminary tests at Beaver Falls was to determine the maximum proportion of Georgia clay that could be used in a commercial wall tile. The tests made at the Ohio State University showed that at least comparatively large proportions could be used in bodies of high absorption before the color was affected. What effect a large proportion would have on other pyrophysical properties of wall tile had next to be determined.

MATERIALS USED.

The materials used in this investigation were as follows:

English china clay.—Moore & Munger's M. W. M. No. 2.

Ball clay.—Kentucky No. 4.

Florida kaolin.—Edgar Plastic Kaolin Co.

Flint.—Pennsylvania Pulverizing Co.

Feldspar.—Pennsylvania Feldspar Co.

Treated Georgia kaolin.—Georgia Kaolin Co.

As these tests were to form the basis of larger commercial tests at the Mosaic Tile Co. plant, it was thought advisable to determine the fineness of grain of the flint and feldspar in order that the shrinkage and absorption could be controlled on changing to a different feldspar and flint. The mechanical analyses were made with a Schultze elutriation apparatus [a] having an overflow of 80° c. c. per minute, and are given in Table 6.

TABLE 6.—*Results of mechanical analyses of feldspar and flint.*

Residue.	Average diameter of grain.	Feldspar in residue.	Flint in residue.
Residue on sieves:	*Mm.*	*Per cent.*	*Per cent.*
On 120-mesh	0.186	9.46	0.60
On 150-mesh	0.157	0.90	0.42
On 200-mesh	0.110	7.50	1.56
On 260-mesh	0.0765	10.70	9.30
On 330-mesh	0.578	9.36	4.32
Residue from elutriator jars:			
In No. 1 jar	0.034	20.84	25.74
In No. 2 jar	0.0187	9.60	18.00
In No. 3 jar	0.010	10.80	19.06
Overflow from No. 3 jar		20.84	20.40

COMPOSITION OF BODIES.

The percentage composition of the bodies compounded from the above white-burning materials, and the physical properties of the bodies are shown in Table 7.

[a] For description of apparatus, see Watts, A. S., Mining and treatment of feldspar and kaolin in the southern Appalachian region: Bull. 53, Bureau of Mines, 1913, p. 46.

TABLE 7.—*Composition and physical properties of bodies used in tests.*

COMPOSITION.

Item.	Series A, body No.—					Series B, body No.—			Series C, body No.—		
	10	11	12	13	14	15	16	17	18	19	20
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Feldspar	15.0	15.0	15.0	15.0	15.0	13.0	12.0	11.0	12.0	12.0	12.0
Flint	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Florida kaolin	10.0	10.0	10.0	10.0	10.0	11.0	11.0	12.0	......	......	......
Kentucky ball clay	15.0	15.0	15.0	15.0	15.0	16.0	16.0	15.0	15.0	15.0	......
English china clay	20.0	15.0	10.0	5.0	......	......	5.0	......	33.0	......	......
Treated Georgia kaolin	......	5.0	10.0	15.0	20.0	20.0	16.0	20.0	......	33.0	48.0
Whiting	......	......	......	......	......	......	......	1.0	......	......	......
Magnesite	......	......	......	......	......	......	......	1.0	......	......	......

PHYSICAL PROPERTIES.

Item.	10	11	12	13	14	15	16	17	18	19	20
Shrinkage	9.70	9.57	9.37	9.15	8.51	6.39	6.10	5.76	6.74	4.59	3.41
Absorption	6.75	7.52	7.98	8.70	9.65	12.44	12.65	12.27	10.02	13.86	17.70
Shade (color) [a]	D	D	D	D	D	B	B	B	C	C	A

[a] Comparative, A is the whitest shade, D the darkest.

PREPARATION OF BODIES.

The weight of each ingredient to be taken was determined from the percentage composition, figured on the basis of a 10-kilogram body, and the total weight was checked by mixing the ingredients and weighing the batch. The bodies were blunged for five hours in a small blunger constructed from an ice-cream freezer; then the slip was passed through a 120-mesh sieve and filter-pressed in a small laboratory press. The press cakes were dried at 110° C. and then ground to pass a 20-mesh sieve. Thirteen per cent of water was added to the ground body, which was then thoroughly mixed by hand, and the moist clay reground in a small dust mill to pass a 30-mesh sieve. The finely ground clay was stored in stoneware jars and allowed to stand overnight.

MAKING THE TILE.

The bodies were pressed into standard 6 by 3 inch tile on an ordinary hand screw press. In order to obtain uniform pressing, all bodies were pressed by the same experienced pressman. Thirty tile were pressed from each body and divided into six sets of five tile each for distribution in different sections of the kiln.

BISCUIT BURN.

The tile were set in saggers in the ordinary manner. Each sagger contained five tile of each body composition, and were distributed in the kiln as follows: A, bottom of first ring, just above bog wall; B, top of first ring; C, bottom of second ring; D, top of second ring; E, bottom of third ring; G, top of third ring.

A plate containing Seger cones Nos. 9, 10, 11, and 12 was placed in each sagger. The heat treatment that the bodies in different sections of the kiln received was as follows:

Temperatures in different sections of kiln, as shown by Seger cones.

Kiln section.	Cone No.	Kiln section.	Cone No.
A	13	D	10
B	11	E	[illegible]
C	11	G	12

The burn was made in an ordinary down-draft Rivers kiln. The variation in temperature shown in the above table was due to a change in burners.

GLOSS BURN.

One tile of each body composition from each section of the biscuit kiln was glazed with the regular glaze used by the company. The glaze was applied by dipping.

VITRIFICATION.

A study of the vitrification was made by the determination of average absorptions and shrinkages. The absorption was determined by soaking the biscuited tiles in distilled water for 48 hours and calculating the percentage of water absorbed by each tile on the basis of the dry weight of the tile. The shrinkage was determined by measuring the length of the burned tile and expressing the difference between the green length (length of die) and the burned length in terms of percentage of green length. The different heat treatments which the test pieces in different sections of the kiln received had a decided effect on the absorption and shrinkage. This may be emphasized by the actual results of tests with body 18, which were as follows:

Results of absorption and shrinkage tests with body 18.

Tile in kiln section—	Average absorption.	Average shrinkage.
	Per cent.	*Per cent.*
A	7.94	7.43
B	10.19	6.90
C	9.75	6.88
D	10.66	6.55
E	12.30	5.83
G	9.29	6.88

The average shrinkage and absorption for each body have been given in Table 7.

DETERMINATION OF COLOR.

As there is no standard method of measuring the shade or color of a wall tile, the shade of the glazed trials was determined by comparison. The results are given in Table 7, A being the whitest shade and D the darkest.

RESULTS OF TESTS.

The purpose of the tests in series A, Table 7, was to study the effect of substituting treated Georgia kaolin for English china clay. The results show that as the content of Georgia kaolin was increased the vitrification was decreased, but no change in color was noted. All the bodies of this series had too high a shrinkage and too low an absorption for practical wall tile, as most commercial wall tile have a shrinkage of about 4.5 per cent and an absorption of 14 per cent.

The tests in series B, Table 7, were designed to decrease the vitrification shown by members 13 and 14 of series A. The data show that the shrinkage was reduced and the absorption increased, but not sufficiently to approximate those of commercial wall tile. An improvement in color, owing to decreased vitrification, was noted. Introducing 1 per cent of whiting and 1 per cent of magnesite did not improve the color of the tile.

The purpose of series C, Table 7, was to further reduce the vitrification by substituting treated Georgia clay for Florida kaolin and ball clay. The results speak for themselves. In bodies 18 and 19 33 per cent of treated Georgia kaolin was substituted for 33 per cent of English china clay without impairing the color of the glazed product. Another interesting fact was the improvement in color caused by substituting treated Georgia kaolin for ball clay in body 20, and in spite of the fact that the content of Georgia kaolin was 48 per cent of the body composition. The shrinkage and absorption of body 19, consisting of 12 per cent feldspar, 40 per cent flint, 15 per cent Kentucky ball clay, and 33 per cent treated Georgia kaolin, approximated that of commercial wall tile, and was therefore used as a basis for further investigations of wall-tile bodies.

LARGE-SCALE TESTS.

In the preliminary tests at the Beaver Falls plant the treated Georgia kaolin gave such promise of being an ideal clay for wall-tile manufacture that large commercial tests were thought advisable. These tests were carried on at the plant of the Mosaic Tile Co., Zanesville, Ohio.

MATERIALS.

The materials used in this investigation were as follows:

Flint.—Pennsylvania Pulverizing Co.

Feldspar.—Pennsylvania Pulverizing Co.

Florida kaolin.—Edgars Plastic Kaolin Co.
Ball clay.—Cooley ball clay.
Treated Georgia kaolin.—Georgia Kaolin Co.

COMPOSITION OF BODIES.

The percentage composition and physical properties of the bodies included in this investigation are given in Table 8.

TABLE 8.—*Composition and physical properties of bodies used in large-scale tests.*

COMPOSITION.

Item.	Series A, body No. —		Series B, body No. —									Series C, body No. —
	43	44	45	46	47	48	49	50	51	52	53	54
Flint.............per cent..	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	37.5	35.0	35.0	35.0
Feldspar..............do....	13.0	00.0	13.0	14.0	14.0	11.0	15.0	16.0	14.0	14.0	14.0	13.0
Cornwall stone........do....	0.0	14.0	0.0	......	......	......	......	......	......	......	......	......
Florida kaolin........do....	12.0	11.0	12.0	11.0	6.0	......	......	......	......	......	......	......
Ball clay.............do....	0.0	0.0	0.0	......	5.0	11.0	5.0	......	13.5	16.0	10.0	14.0
Treated Georgia kaolin, per cent..................	35.0	35.0	35.0	35.0	35.0	35.0	40.0	44.0	35.0	35.0	41.0	38.0

PHYSICAL PROPERTIES.

Item.	43	44	45	46	47	48	49	50	51	52	53	54
Shrinkage........per cent..	3.00	3.00	5.28	5.44	5.92	6.40	6.56	7.20	6.88	7.84	7.52	4.67
Absorption...........do....	17.70	18.00	17.09	17.19	15.10	14.25	14.19	15.19	14.74	14.21	15.37	14.40
Breaking strength.pounds..	45.0	52.0	55.1	55.5	68.5	81.0	71.7	76.5	85.0	100.8	87.0	70.0
Relative shade (color).....	A	A	......	......	......	......	......	......	......	......	......	D

PREPARATION OF BODIES.

The bodies in series A and C, consisting of 3,000-pound batches, were prepared as follows: The total batch was blunged in a double blunger for one hour in the ordinary wet way and then the slip was passed through a 120-mesh vibrating screen into an agitator, from which it was pumped into the filter presses. The filter-press cakes were dried in a tunnel drier heated by the waste heat from cooling kilns and then crushed into small pieces in a set of rolls. About 11 per cent of water by weight was added to the crushed body and after standing for several hours it was finely ground in an ordinary dust mill of the fan type. The finely ground clay was collected in a large storage bin; from this bin it was taken to the presses.

The batch weight of the bodies in series B was only 8,000 grams, and they were prepared as follows: (1) The ingredients were weighed out and the total weight checked by weighing the batch. The clay was (2) blunged in porcelain-lined ball mills for 1 hour, (3) sieved through a 120-mesh screen, and (4) the slip concentrated in plaster absorption bowls lined with muslin, and dried completely in a drier. The dried clay was (5) crushed to pass a 20-mesh screen, (6) tempered

by the addition of 11 per cent of water by weight, and the tempered clay was (7) ground to pass a 20-mesh screen, and (8) allowed to stand for several hours in a covered jar.

MAKING THE TILE.

The bodies were pressed into 3 by 6 inch and 6 by 6 inch tile on the power presses of the tile company.

BURNING.

The tile after being allowed to dry for about four days were set in saggers and biscuit burned at cone 11. The biscuited tile were then glazed with the regular glaze used by the company and gloss burned at cone 02.

RESULTS OF TESTS.

The absorption, shrinkage, and color data given in Table 8 were obtained in the same manner as in the preliminary tests. The breaking strengths given in this table were obtained by determining the weight that would break the biscuited tile with one end gripped between two steel plates. The weight was suspended $2\frac{1}{2}$ inches from the point of support.

The object of the tests in series A, Table 8, was to compare the effects of feldspar and Cornwall stone in wall-tile bodies. The data in the table show that it takes 1 per cent more Cornwall stone to produce the same vitrification, but the stone increases the strength of the body about 15 per cent. The bodies of this series had too high an absorption, too low a shrinkage, and too low a breaking strength for good commercial wall tile.

The purpose of the tests in series B, Table 8, was to obtain a body of higher breaking strength. By comparing body 45 of this series with body 43 of series A it is seen that grinding a body in a ball mill, instead of blunging it, increased the shrinkage but had little effect on the absorption. The breaking strength was greatly increased by substituting ball clay for Florida kaolin, and by increasing the clay content at the expense of the flint a further increase in strength was obtained, reaching a maximum of 100.8 pounds in body 53. As none of the bodies of this series was gloss fired no relative shade or color is given for these bodies.

A large commercial test was made on a body of the composition of No. 54, in series C of Table 8. This body proved to be a good commercial wall-tile body. The low breaking strength, 70 pounds, is due to the fact that the finely ground clay was too dry when pressed. The color of the glazed tile was as good as that of some of the leading wall tile on the market.

APPLICABILITY OF REFINED GEORGIA KAOLIN IN WALL-TILE BODIES.

Treated Georgia kaolin can be substituted for all the English china content and a part of the ball-clay content in clay bodies without impairing the color of the burned product.

Cornwall stone makes a stronger body than feldspar, but a feldspar wall-tile body can be made that is as strong as any commercial wall tile on the market, provided that the total clay content is at least 52 per cent, of which 10 per cent is ball clay and the other 42 per cent is treated Georgia kaolin.

ACKNOWLEDGMENT.

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